Assessing the Macroeconomic Importance of Gasoline and Vehicle Spending

Argonne National Laboratory

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ABSTRACT

Vector error correction (VEC) was used to test the importance of a theoretical causal chain from transportation fuel cost to vehicle sales to macroeconomic activity. Real transportation fuel cost was broken into two cost components: real gasoline price (rpgas) and real personal consumption of gasoline and other goods (gas). Real personal consumption expenditure on vehicles (RMVE) represented vehicle sales. Real gross domestic product (rGDP) was used as the measure of macroeconomic activity. The VEC estimates used quarterly data from the third quarter of 1952 to the first quarter of 2014. Controlling for the financial causes of the recent Great Recession, real homeowners' equity (equity) and real credit market instruments liability (real consumer debt, rcmdebt) were included. Results supported the primary hypothesis of the research, but also introduced evidence that another financial path through equity is important, and that use of the existing fleet of vehicles (not just sales of vehicles) is an important transport-related contributor to macroeconomic activity. Consumer debt reduction is estimated to be a powerful short-run force reducing vehicle sales.

Findings are interpreted in the context of the recent Greene, Lee, and Hopson (2012) (hereafter GLH) estimation of the magnitude of three distinct macroeconomic damage effects that result from dependence on imported oil, the price of which is manipulated by the Organization of Petroleum Exporting Countries (OPEC). The three negative macroeconomic impacts are due to (1) dislocation (positive oil price shock), (2) high oil price levels, and (3) a high value of the quantity of oil imports times an oil price delta (cartel price less competitive price). The third of these is the wealth effect. The VEC model addresses the first two, but the software output from the model (impulse response plots) does not isolate them. Nearly all prior statistical tests in the literature have used vector autoregression (VAR) and autoregressive distributed lag models that considered effects of oil price changes, but did not account for effects of oil price levels. Gasoline prices were rarely examined. The tests conducted in this report evaluate gasoline instead of oil.

The base model VEC results were tested to see if they were robust to inclusion of an oil-based "wealth channel" variable. A recent Council of Economic Advisors report contended that wealth channel economic losses were a dominant cause of U.S. recessions. The variable was a composite in which oil price increases were weighted by the ratio of net imported oil costs to real GDP.

This variable (oilshrp3) combined (and constrained) GLH effects 1 and 3. The Council of Economic Advisors report contended that their modeling results showed that oilshrp3 or similarly constructed fuel price variables represent a dominant cause of U.S. recessions; however, although oilshrp3 was important when added to the base-case multiple-variable VEC model, it did not significantly alter the original results. To an approximation, the addition of the Council of Economic Advisors oilshrp3 variable to our base case models allowed tests for existence (statistical significance) of each of the three effects identified by GLH, as well as a test for changes in magnitude of overall results due to oilshrp3. Consistent with the empirical findings, GLH also imply that important damages will remain due to effects 1 and 2, even when their estimated wealth effect is zero due to an absence of net imports.

In general, model results suggest that *changes* in gasoline price and quantity as well as gasoline price and quantity *levels* are both important and—when properly accounted for via the VEC estimation method—are together better predictors of subsequent macroeconomic activity than are oil price changes alone. Results also imply that although elimination of United States' oil imports will likely halt long-term United States wealth losses to other nations, this will not protect the United States from other significant short-term damages that result from world oil supply restrictions, nor will it protect the United States from domestic gasoline demand pulses or supply shortfalls that contribute to significant domestic gasoline price increases.

Although they are confined to the post-WWII period, our model results are consistent with the generic theory of Santini: transport cost and technology changes have been fundamental determinants of variation in macroeconomic activity in the United States since its founding. Results are also consistent with the recent world-oil-price-to-macroeconomy arguments of Difiglio: transport costs affect not only vehicle sales, but also equity in built assets such as housing and leisure facilities.

1 SUMMARY OF KEY FINDINGS

1.1 ESTIMATES OF CAUSAL CHANNELS: TRANSPORT COST AND THE MACROECONOMY

A primary purpose of this research was to use the statistical vector error correction (VEC) technique to test for the existence and importance of a theoretical causal chain from transportation-fuel-cost to vehicle-sales to macroeconomic-activity. Real transportation fuel cost was broken into two cost components, real gasoline price (rpgas) and real personal consumption of gasoline and other goods (gas) (see Tables 1 and 2). Real personal consumption expenditure on vehicles (RMVE) represents vehicle sales. Real gross domestic product (rGDP) was used as the measure of macroeconomic activity. The VEC estimates used quarterly data from the third quarter of 1952 to the first quarter of 2014. In order to control for the financial causes of the recent Great Recession, two financial variables were included: real homeowners' equity (equity) and real credit market instruments liability (real consumer debt, rcmdebt). Results supported the primary hypothesis that the causal chain from transportation-fuel-cost to vehicle-sales to macroeconomic-activity exists and is important. The results also introduce evidence that another financial path through equity is important, and that use of the existing fleet of vehicles (not just sales of new vehicles) is an important transport-related contributor to macroeconomic activity. Consumer debt reduction is estimated to be a powerful short-run force reducing vehicle sales.

This report discusses results over three different time periods: (1) short run (two quarters), (2) long run (5 years), and (3) very long run (decades). The VEC methodology first tests for very-long-run linkages among model variables and isolates these before estimating short- and long-run deviations from the very-long-run trends. The initial test is for "cointegration." Multiple tests and variable pairings in different models indicated that cointegration existed between some variables. Such a very-long-run pairing was initially predicted to exist for (1) rpgas and equity and (2) rpgas and gas. The latter pairing is of interest for this study. The base model cointegration predictions for this pairing are shown in Figure 1.

The predicted values for these equations are not expected to be close to actual values. In the VEC model, "shocks"—deviations from the very-long-run path predicted by separating changes relative to the cointegration process—are often large and important factors in beginning recessions. Aside from the quiescent 1990s, the gasoline price cointegration equation predicts relatively consistent variability of real gasoline price throughout the estimation period. In fact, the period up to 1972 exhibited relatively little variation, while the post–Organization of the Petroleum Exporting Countries (OPEC) period following exhibited very high variation (Figure 2). This difference raises some questions: What underlying process caused relative price stability prior to 1972? And what process caused variability afterwards? During the earlier period, U.S. oil production represented a far larger share of world production than in the later one. In the earlier period the Texas Railroad Commission (Difiglio, 2014) was effective in manipulating prices and U.S. output.

TABLE 1 Raw Variable Definitions, Units, and Source

Variable	Definition	Units	Source
DGOERC1	Gasoline and other energy goods	Billions of dollars	Bureau of Economic Analysis
DGOERG3	Price index for gasoline and other energy goods	Index number, 2009 = 100	Bureau of Economic Analysis
DPCERC1	Personal consumption expenditures	Billions of dollars	Bureau of Economic Analysis
DPCERG3	Price index for personal consumption expenditures	Index number, 2009 = 100	Bureau of Economic Analysis
A191RC1	Gross domestic product	Billions of dollars	Bureau of Economic Analysis
B191RG3	Price index for gross domestic product	Index number, 2009 = 100	Bureau of Economic Analysis
cmdebt	Households and nonprofit organizations; credit market instruments; liability	Billions of dollars	Federal Reserve Economic Data
cpiaucsl	Consumer price index for all urban consumers: all items	Index number 1982–84 = 100	Federal Reserve Economic Data
oehrenwbshno	Households; owners' equity in real estate	Billions of dollars	Federal Reserve Economic Data
DMOTRC1	Motor vehicle and parts expenditures	Billions of dollars	Bureau of Economic Analysis
DMOTRG3	Price index for motor vehicle and parts	Index number, 2009 = 100	Bureau of Economic Analysis

Despite their large inconsistency with actual short-run price movements, the cointegration equation predictions provide insight with regard to important very-long-run trends. Quarter-to-quarter real gasoline price variation is far larger than real spending variation, which is consistent with a short-run inelastic response of real gas spending (the variable gas, which is an approximation of quantity) to real price.

However, over the very-long-run (full period) the average rate of predicted rpgas (real price) growth was 0.09% per quarter, which is *less* in absolute terms than the average rate of predicted real gasoline spending (gas) decline (–0.14% per quarter). Thus, the cointegration equation implies that over the very long run the United States' annual rate of reduction of real gasoline spending was absolutely greater than the annual rate of increase of real gasoline price. Over the very long run, as a result of capital for energy substitution, the response of consumption of gasoline to real gasoline price was elastic. The Council of Economic Advisors to the President

TABLE 2 Model Variables and Definitions

Model Variables	Definitions
lnequity	Real equity—Natural logs: ratio of nominal owners' equity to the consumer price index for all urban consumers (ln [oehrenwbshno] – ln[cpiaucsl])
lnrpgas	Real price of gasoline—Natural logs: ratio of the nominal gasoline and other energy goods price index to the personal consumption expenditure price index (ln [DGOERG3] – ln[DPCERG3])
lnrcmdebt	Real consumer debt—Natural logs: ratio of nominal households' credit market instruments liability to the consumer price index for all urban consumers (ln[cmdebt] – ln[cpiaucsl])
lnRMVE	Real motor vehicle expenditure—Natural logs: ratio of the nominal motor vehicle and parts expenditures to the price index for motor vehicles and parts (ln[DMOTRC1] – ln[DMOTRG3])
lngas	Real gasoline and other goods spending—Natural logs: ratio of nominal gasoline and other energy goods expenditure to the price index for gasoline and other energy goods (ln[DGOERC1] – ln[DGOERG3])
lnrGDP	Real GDP—Natural logs: ratio of nominal gdp to gdp price index (ln[A191RC1] – ln[B191RG3])
oilshrp3	Council of Economic Advisors composite measure of a "wealth channel" variable weighting oil price changes (West Texas Intermediate Oil) by share of net imported oil spending in GDP

FIGURE 1 Base Model Cointegration Equation Predictions (fractional change per quarter)
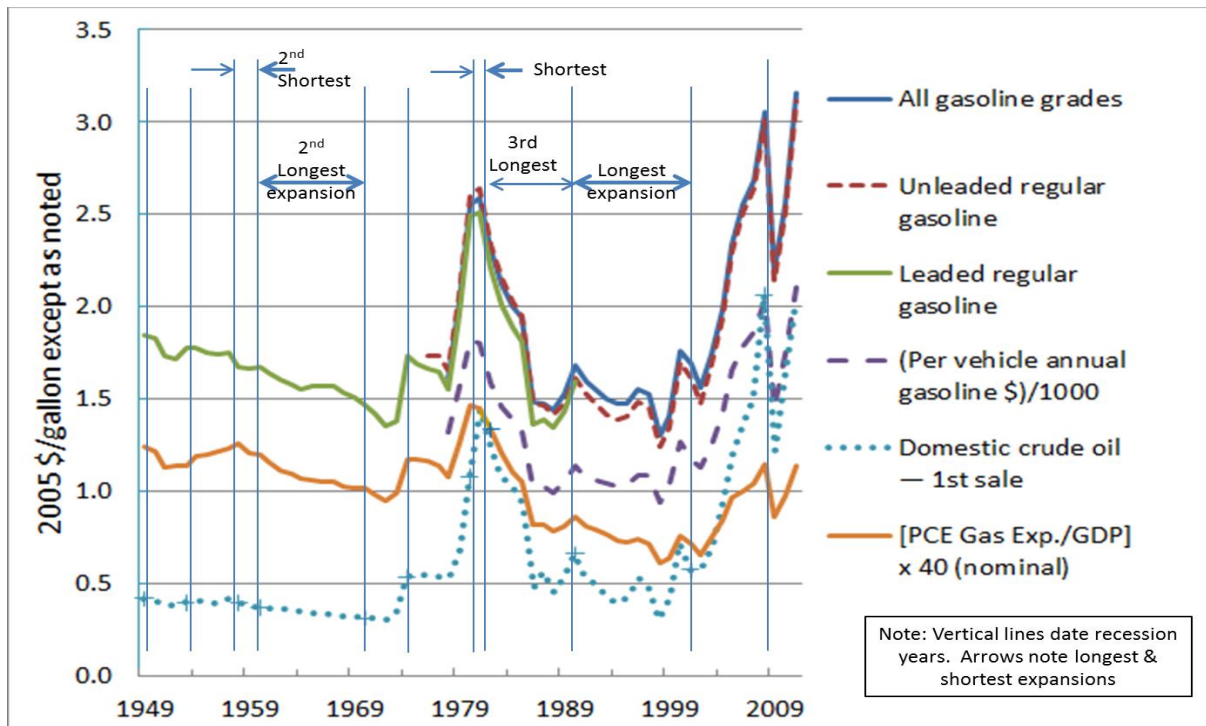
FIGURE 2 Patterns of Gasoline and Oil Prices and Expenditure Shares from 1949 to 2011

of the United States' 2014 report recognized that the very-long-run and the short-run responses to oil prices will be very different. It stated that:

> "Although capital and labor substitute for energy in the long run, in the short run they can be complements in production because of fixed technologies, so higher energy costs can result in layoffs in energy-intensive firms and industries."

The very-long-run reductions in gasoline consumption predicted by the gas cointegration equation were likely due to a United States scientific, engineering-management, and legal/regulatory culture that placed a high value on improvement of thermodynamic efficiency. Such improvements are primarily created through strategies and techniques employed by the engineering and management professions. However, although the cointegration equation predicts a relatively smooth process, we assert via graphics and description that the actual process of substitution is very long-term and uneven. We argue that it is spurred on by repeated year-over-year transport fuel cost increases taking place for several years. When consumers and businesses expect high transport fuel costs to be permanent, capital is substituted for energy in new transportation technology over 5- to 10-year intervals (Bandivadekar et al., 2008; Santini, 1984, 1986, 1992; EPA, 2015). However, the 5- to 10-year bursts of adoption are accelerations of disruptive technological change that is already underway (Christensen, 2003). Technologies placed into small niche markets between transport fuel cost shocks are developed despite a lack of general near-term economic viability. Those profitable or initially money-losing niche market placements, which are often speculative, are due in part to the strong U.S. scientific-engineering-management orientation toward the intergenerational achievement of thermodynamic efficiency,

and to long-lasting legal intellectual rights that enable monopoly power to ultimately pay for new technology development projects. This very-long-run process is outside the scope of traditional economic growth modeling (Solow, 1987).[1]

Results were also consistent with research that contends that positive gasoline price shocks and subsequent short-run vehicle sales declines have consistently and significantly contributed to recessions (Santini, 1984; Hamilton, 1988; Kilian, 2008; Edelstein and Kilian, 2009; Ramey and Vine, 2010). However, the results here also provide a new perspective, enlarging the estimated extent of economic damage caused by transport cost increases. Kilian (2008), Edelstein and Kilian (2009), and Ramey and Vine (2010) demonstrated the causal chain from gasoline price to vehicle spending, but not the step from vehicle spending to macroeconomic activity. We (Santini and Poyer, 2013) recently used the VEC statistical technique to demonstrate the existence of this path from vehicle sales to total national employment. This paper demonstrates a short-run effect of RMVE on rGDP, but also infers that reduced use of the fleet of existing vehicles is an important and longer-lasting predictor of reduced GDP.

Another nuance revealed by this analysis is the role of consumer debt reduction in causing vehicle sales declines. The model indicated that chosen (perhaps imposed) consumer debt declines competed with very-long-run tendencies toward vehicle spending increases; the vehicle debt issuance declines win in the short run, causing a sharp net reduction in value of vehicle sales. This pattern is broadly consistent with Santini's theories about the process of major capital for energy substitution in the transport sector, when spurred by significant transport fuel price increases. Generally, Santini observes that such capital for energy substitution occurs with sharp step function changes in transportation technology that are empirically (Santini, 1984, 1985b, 1985c, 1988) and theoretically (Santini, 1985b, 1985c, 1986, 1992), associated with multi-year periods of unusually slow average macroeconomic growth. Dramatic cessation of purchase of transportation equipment associated with increase savings (decreased borrowing) are a predicted behavior. The identified periods typically span events with unusually dramatic changes in financial market funds flows and valuations.

None of the previously cited papers tested for effects of real gasoline spending on macroeconomic activity. In 1987 and 1994, Santini found that measures of energy use were better 1- to 2-year predictors of real GDP than were various energy prices. The VEC estimates presented here also imply that real gasoline spending (gas) by consumers is an extremely important short- (6-month) and long-run (5-year) contributor to real GDP. However, as noted in the discussion of the cointegration equations and the capital for energy substitution process, real gasoline spending reduction per unit of real GDP has been implemented for the very long run. In the short- and long-run (but not very-long-run) time periods, real gasoline spending is probably a reasonable proxy for transport services obtained. It is reasonable to hypothesize that vehicle

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[1] The idea that technology shocks might be contractionary has been fairly recently examined by Basu et al. (2006). The idea that technology shocks might explain aggregate fluctuations was also proposed by Galí in 1999. Santini's proposition is far more specific with respect to the kind of technology shock that matters.

miles of travel would provide a more consistent measure of macroeconomic benefit in short-, long-, and very-long-run time periods.[2]

The usual VEC outputs analysts present and discuss are impulse response functions (IRFs). In this case, we present what are called "orthogonal impulse response functions (OIRFs)," which are designed to eliminate any contemporaneous influence from other variables in the estimated system.

For this study, the primary goal was to move to an understanding of the contribution of transportation fuel cost changes to short-run macroeconomic performance. The VEC technique is chosen because of its theoretical superiority in sorting out short- and long-run effects from very-long-run linked trends. A fundamental question was whether or not transportation fuel cost "shocks" are a primary cause of recessions. To date, this study has examined rpgas and real gas spending separately. Aside from descriptive and graphic investigation, it has not tested for effects of changes of gasoline expenditure share on rGDP. Kilian (2008) and Edelstein and Kilian (2009) constructed a variable that *weighted* real gasoline price increases by consumer expenditure share. The design of this variable is the same as that adopted in the "wealth effect" variable from the recent Council of Economic Advisors "All of the Above" report. Among econometric/statistical references cited, aside from Santini (1987), no one has examined the effects of changing consumer expenditure share itself (and neither has this study). However, we included anecdotal comparison of the three distinct multi-year gasoline spending share increases shown in Figure 2 (orange line), as well as a discussion of their role in accelerating very-long-run capital for energy substitution.

Our recent conference paper (Poyer and Santini, 2014) plotted the change of consumer expenditure share leading into the Great Recession (Figure 3). From 2002 to 2008, gasoline expenditure share rose by ∼75%, with Δ ∼ 1.7%. In Figure 4, the gasoline expenditure share for the 1969–1986 period is plotted. From 1972 to 1980, gasoline expenditure share rose by ~53% with an increment (Δ) of about 2%. At the end of this expenditure share increase, a "double dip" pair of closely spaced recessions occurred. The Great Recession was worse because of overleveraging and severe financial problems in the housing sector, but about the same cumulative incremental personal consumption gasoline expenditure share rise occurred leading up to both the double dip recessions and the Great Recession.

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[2] One hypothesis to test is whether or not the oil price increases of 1973–1981 led to a structural break with respect to trends in gasoline consumption per capita. Gasoline consumption per capita rose dramatically from 1960 to 1978 (2.58%/year) but shifted to negative change (–0.74%/year) (http://www.indexmundi.com/facts/united-states/road-sector-gasoline-fuel-consumption-per-capita) after implementation of dramatic improvements in fuel efficiency from 1978 to 1984, promoted by Corporate Fuel Economy Standards. Although there was a clear downward inflection point in gasoline consumed per capita after 1978, there was no downward inflection point in vehicle-miles-of-travel (VMT) per capita until 2007, within the second of the major oil price run-ups shown in Figure 2 (McCahill and Spahr, 2013; http://www.ssti.us/wp/wp-content/uploads/2013/10/VMT_white_paper-final.pdf).
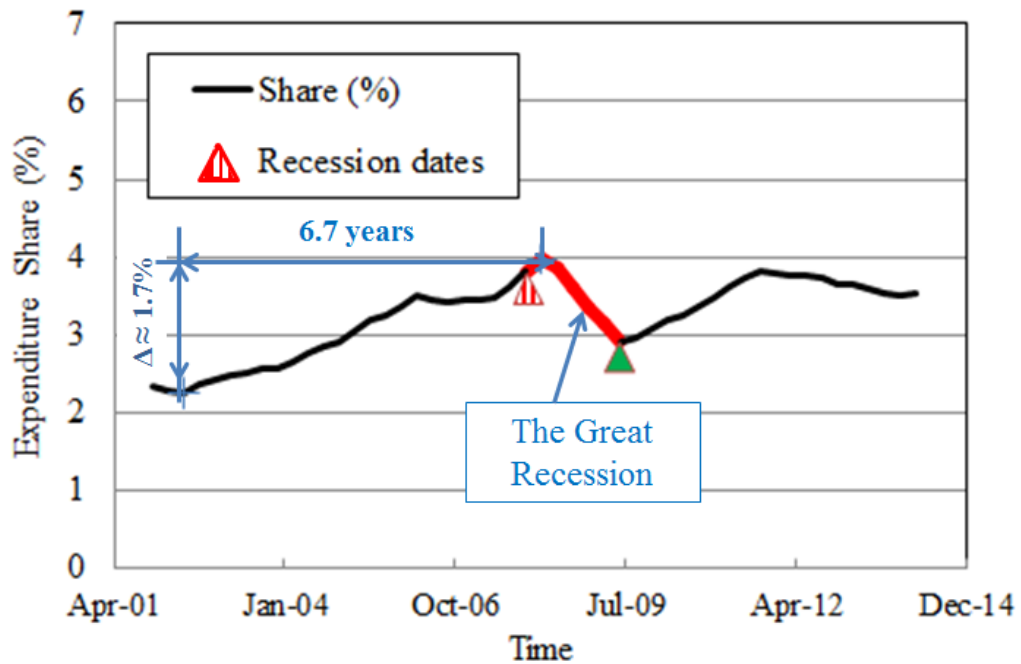
FIGURE 3 Very-Long-Run Change in Gasoline Expenditure Share Leading into the Great Recession
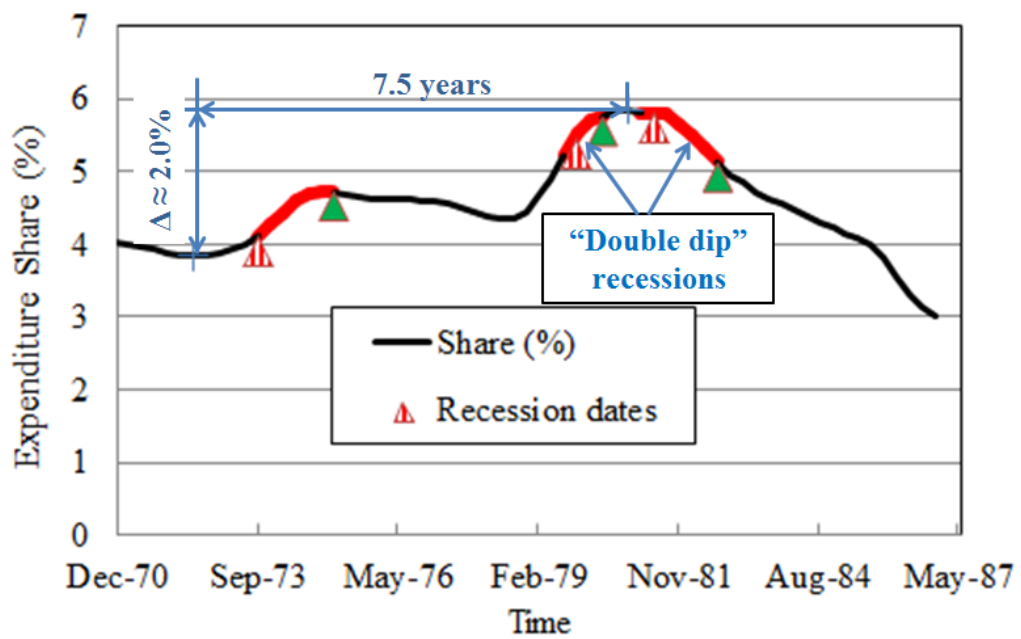
FIGURE 4 Very-Long-Run Change in Gasoline Expenditure Share Leading into the 1980–1982 "Double Dip" Recessions

Figure 2 (orange line) illustrated that a notable change in the gasoline expenditure share of GDP also occurred from 1950 to 1958. This share increase was also followed by two unusually closely spaced recessions. Consistent with the smaller magnitude of this share increase, the two recessions were individually and cumulatively much less severe. This is an interesting case in the sense that the share increase was clearly not price related; an increase in gasoline consumption was the key factor. There was a significant 1953–1957 per-car increase in cost due to size and horsepower, followed by a 1957–1958 car production collapse (-32%) and the first of the two previously mentioned recessions in 1958 (Fisher et al. 1962).

These patterns of multiple-year gasoline expenditure share increases followed by unusual macroeconomic difficulties are consistent with the "Energy Squeeze" perspective argued by Santini (1985a). Each of these periods of rising expenditure shares was very long run by the definition used here (more than 5 years). These more severe recessions or recession pairs end a very-long-run sustained increase in consumer spending share for transportation fuels. However, not all recessions occur at the end of such unsustainable very-long-run spending share increases. For other recessions, relatively short-run transportation fuel cost increases often play a role.

1.2 MITIGATING THE SHORT-RUN COLLAPSE OF TRANSPORT SPENDING LEADING INTO RECESSIONS

The discussion of the 1950s consumption-induced consumer gasoline spending share increase illustrates the importance of taking account of not only the real price of gasoline (rpgas), but also real consumption of gasoline. To close short-run gaps between gasoline demand and supply, a transportation fuel reserve would be theoretically ideal, since increases in transport cost are a fundamental cause of many mild and all severe macroeconomic contractions. Should demand exceed supply due to cold winters or short-sighted adoption of inefficient vehicles, then a reserve can fill the demand-induced gap until the winter is over or consumers can shift to more efficient vehicles.[3] Should supply fall short of demand due to a war in the Middle East or a successful effort by OPEC to restrain supplies, then a transport fuel reserve could provide some "cushion" while consumers adjust. Adjustments of new vehicle fuel efficiency by automakers take much more time and have only a small effect on the fleet's inherent fuel efficiency in the short run.

Greene, Lee, and Hopson (2012) (GLH) recently estimated three distinct negative economic effects resulting from dependence on imported oil whose price is manipulated by OPEC. The three negative effects are due to (1) dislocation (positive oil price shock), (2) high oil price levels, and (3) quantity of imports times price delta (cartel price less competitive price) (wealth effect). The VEC approach is tailored to capture the first two. Note that two of the effects are attributed entirely to price, one partially to price, and none to quantity of personal gasoline (or oil) consumption. The wealth effect does rely on national quantity of oil imports. The Council of Economic Advisors (2014) infers that their estimate of the wealth effect may be the dominant cause of macroeconomic dislocations. Unlike GLH's disaggregation of their wealth

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[3] Adjustment of the use of large vs. small existing vehicles may have a significant effect, but available data are inadequate to estimate these effects (Energy Information Administration, 2015, Table 1.8).

effect estimate from their dislocation effect estimate, the Council of Economic Advisors different wealth effect estimate folds dislocation (price shock) effects together with net import costs. According to either argument, if the quantity of imports goes to zero, the wealth effect disappears. GLH's estimates imply that each of three effects is important, but portions of the Council of Economic Advisors report imply that their composite aggregated estimate of the wealth effect is dominant in causing macroeconomic fluctuations, and that other effects are unimportant.

Our base VEC model does not include any variable designed to address the wealth effect, but it is designed to accurately isolate the GLH "dislocation losses" (what most other authors call shock effects) and price-level effects. In the VEC model, and in the estimates constructed by GLH, the gasoline (oil for GLH) price-level effect can cause an immediate effect on macroeconomic growth. Thus, according to the fundamental structure of the GLH estimates, and of the VEC model, both the dislocation effect and price-level effect can create short-run damage. By mitigating price increases for transportation fuels, a transportation fuel reserve can reduce the theoretical price-induced damages estimated in these two damage effects. GLH used annual data and defined the short run as a year. Difiglio (2014) clearly believes that a year is far too long to react to mitigate an oil price shock. Our VEC modeling addresses both contemporaneous price-level effects and near-term lagged price shock effects over a period of two quarters; thus, the estimates are tailored to determine short-run dislocation (shock; price change) and price-level effects.

Microeconomic theory tells us that a positive, widening gap between demand and supply is the cause of a price increase. Thus, gasoline price increases that reach "shock" magnitude are a consequence of a short-run inability to match demand with supply. The ability to inject supply can reduce the magnitude of positive price shocks and allow productive equipment to continue operation, thereby mitigating macroeconomic damage.

The base VEC model OIRFs indicate that a long-run gasoline price increase immediately leads to short-run sharp reductions in transportation-related spending by consumers (Figure 5). None of the variables return to starting levels in the long run. Real GDP, real gasoline spending, and real debt all decline monotonically throughout the full 5 years. Vehicle sales recover after a few quarters, while equity recovers after more than 2 years have passed. Vehicle spending and gasoline spending drop most sharply after two quarters. However, home equity, vehicle sales, and consumer debt all drop sharply and immediately. Immediate gasoline spending drops even more sharply. Declines in the entire economy (GDP) are far smaller on a percentage basis. Those declines occur more slowly, are worst in the first year, but continue for 20 quarters.

The consequences of the changes in transportation-related spending feed into the next quarter's real GDP level (Figure 6). Although a 1% increase in vehicle spending has more immediate effect on real GDP than a 1% increase in any other variable, delayed benefits of 1% increases of three other variables (gasoline spending, consumer debt, and home equity) each individually are larger. It is important to remember that vehicle spending is very volatile, so changes in vehicle spending in a recovery from a recession are likely to be considerably larger than these other three variables. Gasoline price increase impacts on real GDP (negative) are plotted in both figures.
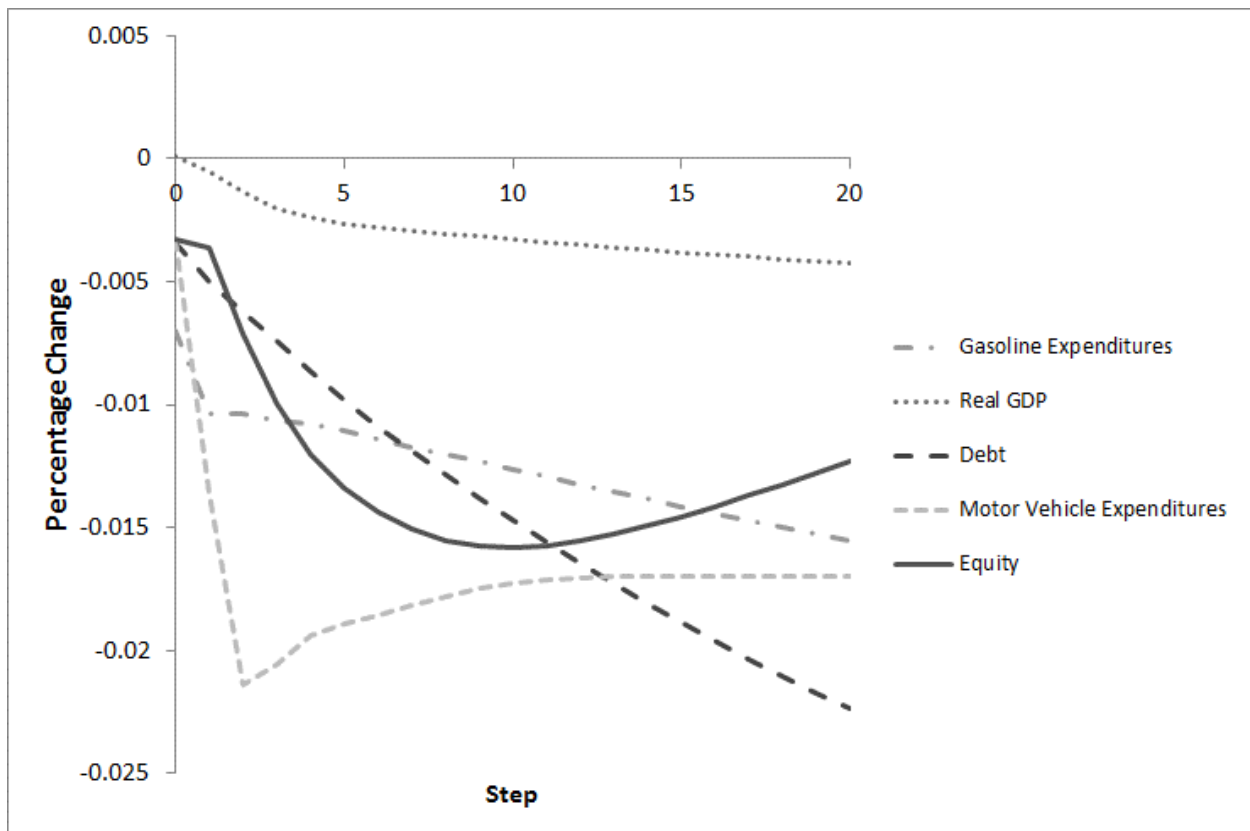
FIGURE 5 Orthogonal Impulse Responses: Effects of a Permanent 1% Gasoline Price Rise on Other Model Variables
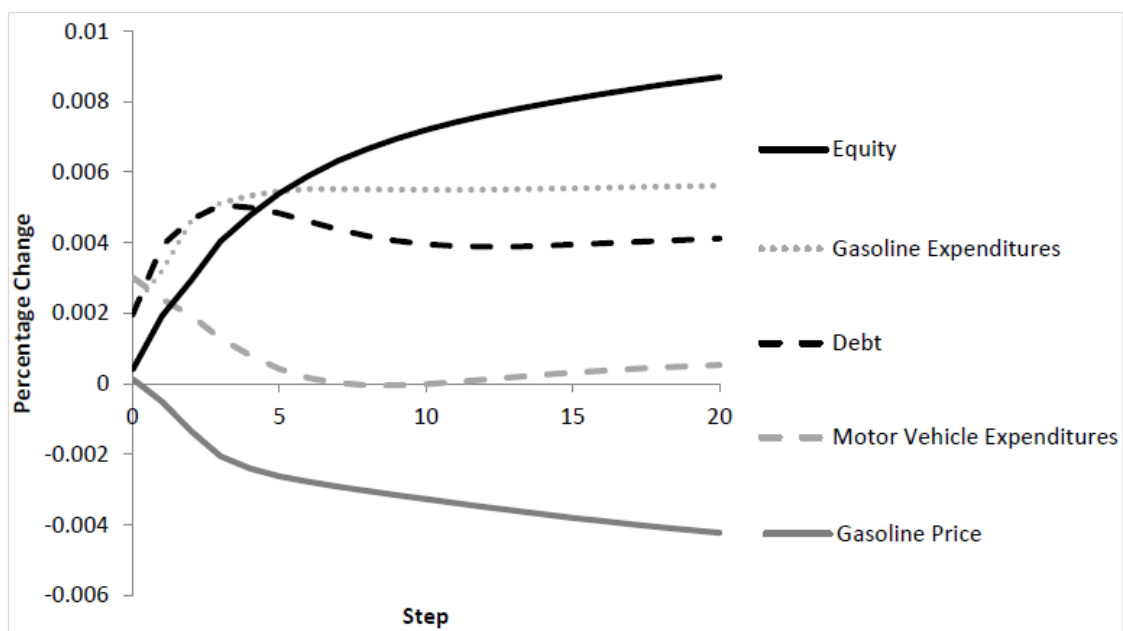
FIGURE 6 Orthogonal-Impulse-Responses: Effects of Other Model Variables (1% change) on Real GDP

The gasoline spending results imply that spending on new vehicles is not the only contributor to a recession; the rate of use of existing vehicles is a factor as well.

Citing a recent paper by Sexton et al. (2012), Difiglio (2014) argued that crude oil price shocks not only affect vehicle sales, they also affect equity in built infrastructure (houses, hotels, resorts) in more remote locations that require long-distance driving. This hypothesis is clearly supported by the OIRF values for home equity in Figures 5 and 6. Thus, discussion has historically focused mostly on vehicle sales, with many analysts contending that the vehicle sales effects were not large enough to be a dominant cause of recessions; however, the possibility that increases in transport cost cause not only direct losses to the transport sector, but also indirect losses of wealth in residential and other built assets, creates the possibility that variation in transport costs is a far more important determinant of variation in macroeconomic output than previously recognized. Accordingly, the importance of promptly mitigating transport fuel cost increases through early injection of reserve supplies may be greater than previously recognized.

A one-region urban housing value model is used by Sexton et al. to examine the Great Recession. Housing values decline with distance from a city center. One of Santini's attempts to understand the economics of changes in transport technology induced by transport fuel price changes (Santini, 1986, 1992) is based on a two-region transport cost model that also suggests that "the extent of the market" shrinks when transport fuel costs rise. The Santini model has no housing sector, per se; instead, it relies on transport economics to explain the decline of land use rent with distance from a central market. Soon after the 1980s double-dip recessions, economic historian Blaug (1985) wondered why the work of several transport economists had not been incorporated into standard economic thought.

1.3 OIL PRICE SHOCKS ALONE VS. GASOLINE PRICE LEVELS AND SHOCKS

Since our base VEC model was not designed to test for the importance of the wealth effect, a first attempt at estimating the importance of the wealth effect was made by inserting one of the wealth-effect variables from the Council of Economic Advisors study. The variable used was the oilshrp3 variable, the strongest of several variables tested by the Council of Economic Advisors. In oilshrp3, the share of dollar value of oil imports within real GDP was used as a weighting factor for oil price increases. The net oil import cost share of the GDP (in dollars) was multiplied by the percentage increase in West Texas Intermediate (WTI) crude oil, a world oil price indicator. Using the WTI percentage increase, price levels were eliminated from the variable. Thus, it would be impossible for the VEC model to tease out WTI price levels from the oilshrp3 variable. In effect, oilshrp3 is a weighted measure of an oil price shock that was hypothesized to be a dominant predictor of GDP and/or personal consumption expenditure.

Oilshrp3 is a variable that is only a shock (dislocation) measure with price level information stripped out. If GLH and VEC model theoreticians are correct about the importance of input variable price levels in predicting changes in output (GDP in this case), then the oilshrp3 variable should fail to eliminate much of the GDP (and other variable) changes predicted.

From another perspective, inclusion of oilshrp3 represents an initial head-to-head competition between the general theory that transport fuel price (gasoline here) is a more meaningful predictor of macroeconomic activity than oil price.

If the oilshrp3 variable, and not gasoline price levels and shocks, was indeed a dominant cause of recessions, then inclusion of oilshrp3 in our base model should have sharply diminished the estimated importance of most variables. This did not happen. In fact, the short-run results for estimated GDP damages from a real gasoline price increase were essentially unchanged (Figure 7). Long-run GDP reduction estimates for real gasoline price declined, implying that the economy can begin recovery in the long run. However, as far as short-run recession mitigation is concerned, the implication is that reduction of real gasoline price impacts remains as important for recession prevention as originally estimated (Figure 7). Further, this plot only addresses effects of real gasoline prices. Oilshrp3 and real gasoline price are two competing energy price variables; both are vying for the lead in explaining recessions.

The VEC imposes a number of estimation issues on the analyst using the software. The ordering of entry of variables can be important. If a variable is placed initially in the order, it is said to be exogenous. If it is placed last in the order, it is endogenous. If placed at intermediate entry points, it is neither. The cointegration relationship assumes that cointegrated variables must be entered first. We tested whether or not oilshrp3 was cointegrated with the change of real price of gasoline. Since both variables are tied to oil price, the fact that they were estimated to be cointegrated is unsurprising; there were signs that coefficients were identical and that measures of statistical significance were also nearly equal.
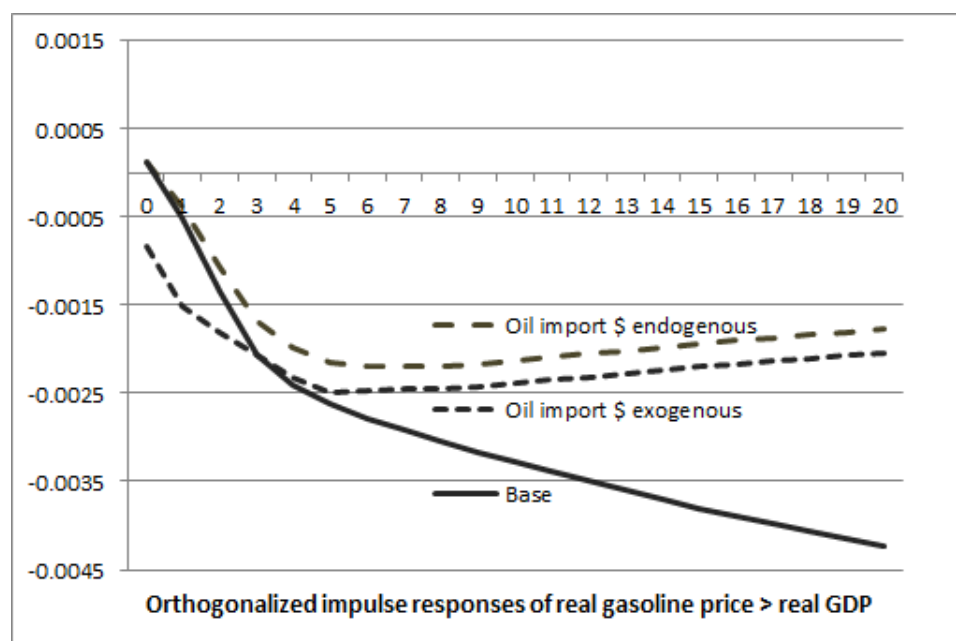
FIGURE 7 Predicted OIRF of Gasoline Price on Real GDP: Base Model vs. Two Wealth Effects Tests

Despite a relatively high correlation between these two energy price variables, the VEC model results clearly imply that one of the two is a better candidate from which to spin off explanatory processes for the beginning of recessions induced by some kind of energy price increase. The OIRFs for the Council of Economic Advisors (2014) hypothetically dominant oilshrp3 variable in our estimates implied a far lower impact on real GDP (Figure 8) than did real gasoline price (Figure 7). The first and second quarter impulse response function of oilshrp3 on GDP was an interesting anomaly; in the initial (contemporaneous) and first quarter, it was estimated that the impulse response was beneficial, increasing real GDP. Thus, considering these OIRFs alone, the implications for recession management were that eliminating the oilshrp3 version of the wealth effect could worsen U.S. recessions caused by world oil price increases.

Considering all variables, the impact of oilshrp3 was often far less than that of real gasoline price (rGDP, gas, rcmdebt). For real motor vehicle spending, the OIRFs were similar; however, for equity the OIRF for oilshrp3 was far greater than for real gasoline price.

Two versions of the base model plus oilshrp3 are presented in Figures 7 and 8. In one case, oilshrp3 is entered into the model first (exogenous). In the other case it is added last (endogenous). The purpose was to bound the possible results. However, detailed examination of results suggests that the assumption that oilshrp3 is exogenous is far more justifiable than that it is endogenous. The results for the exogenous case are worse with regard to the status of oilshrp3 as a single dominant variable explaining recessions.
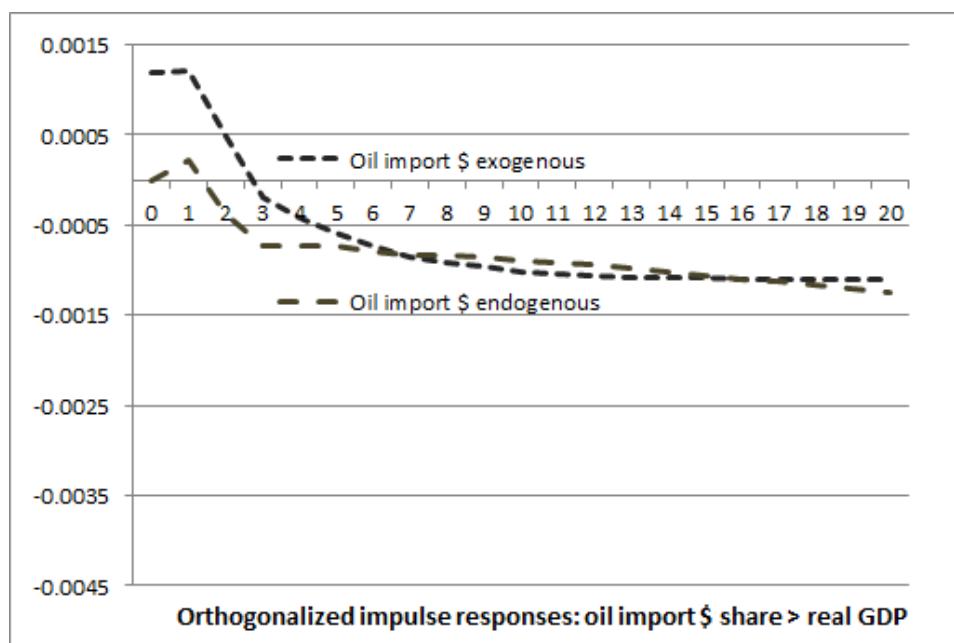
FIGURE 8 Wealth Effect Variable OIRF on Real GDP: Exogenous vs. Endogenous Estimates

Why might the oilshrp3 variable have failed (it is very important, just not dominant) this test? One possibility is the implicit Council of Economic Advisors assumption that importing oil from anywhere in the world is unequivocally bad. The assumptions of GLH are fundamentally different. Their explicit argument is that the importing of oil from OPEC members is to be avoided because the cartel exerts its monopoly power to the detriment of the United States. By constraining output, OPEC is said to cause all three of the negative effects (oil price shock dislocations, cost penalties from high oil prices, and loss of more wealth due to higher costs for purchase of imports) that they discuss, causing havoc in the U.S. economy that could be sharply reduced if the share of world oil imports from OPEC is lowered. GLH recommend that fuel efficiency, alternative fuels, and increased domestic energy production should be pursued. An ideal OPEC would operate competitively, with lower and more stable prices, to the benefit of the U.S. economy and presumably the world. Thus, if OPEC were to behave as the Texas Railroad Commission and the associated leading oil companies of the world from 1949 to 1972, the United States would benefit from importing OPEC oil.

In the case of the oilshrp3 variable, there might be cases where a relatively small oil price shock weighted by a large amount of net imports sold at a low price could cause as much of an increase in oilshrp3 as a much larger shock weighted by a small amount of imports sold at a high price. In the GLH model, and from Difiglio's world oil market perspective, the world oil price shock in the second case would probably be far more damaging than for the first case.

Of course it is also possible that the best-designed oil price variable will prove to be less useful in future modeling of U.S. macroeconomic fluctuations than a well-designed transport fuel price variable. Notably, although many manipulations of oil prices have been made in the literature to improve the fit of the theory that fundamentally oil matters, transportation fuel price manipulation and assessment has just begun.

1.4 CONCLUSIONS

We infer that transportation fuel cost shocks (resulting from real gasoline price and real gasoline spending) are far more important determinants of macroeconomic activity than previously recognized. When both real gasoline price and real gasoline spending combine in the very long run (more than 5 years) to create a large net increase in share of consumer spending on gasoline, unusually severe and/or frequent recessions are likely to follow the multi-year run-up.

In 1981 John Tatom predicted that permanent oil price shocks would permanently retard economic growth. Decades later, using an econometric technique that did not exist at the time, our model estimates are consistent with Tatom's prediction.

Transportation fuel price and expenditure are cointegrated in the very long run. The estimated cointegration equation implies that over decades real transportation fuel expenditures are elastic with respect to transportation fuel price. The hypothesis is that a U.S. scientific-engineering-management culture and system (patents, long-term research and development, intellectual property rights) that value sustained efforts to improve thermodynamic efficiency

enables intermittent bursts of technology transition (capital for energy substitution) in response to very-long-run (more than 5 years) transportation fuel spending share increases.

Although financial problems created by overleveraging are undoubtedly what made the latest recession the "Great Recession," the changes in gasoline spending share that contributed to the recession were as bad as those that preceded the double-dip recessions of 1980–1982, which together also resulted in a very severe long-run macroeconomic contraction. The impulse response function ordering of changes of the chosen variables indicates that transport fuel cost increases cause short-run transportation spending declines (vehicles and fuel). These are consistent leading events associated with the many recessions in the sample period. However, both equity and consumer debt also decline immediately and significantly; they have similarly proportionate changes relative to real gasoline spending and real motor vehicle spending after about 2.5 years.

The wealth effect emphasized in a recent 2014 report by the Council of Economic Advisors is only one of the three macroeconomic damage effects related to oil price, as identified by GLH. Consistent with the estimates of GLH, dislocation (price shock) and price-level effects remain very important, even if the wealth effect is eliminated. Estimates of the base VEC model were compared to models modified to test whether a wealth effect variable chosen by the Council of Economic Advisors would alter our findings. The expanded model estimates indicated no short-run benefit of elimination of the wealth effect by eliminating net imports. Thus, in the short run, the VEC estimates imply that shock and price-level effects (not wealth effects) dominate the damages from the associated gasoline and oil price increases caused by transport fuel demand that exceeds supply.

Our comprehensive transport-cost-related dynamic description of the macroeconomy using six variables in a VEC model produced a set of impulse responses relatively robust when the composite "wealth effect" oil price shock variable was added. Consistent with the underlying theory that variation in transport cost dominates macroeconomic fluctuations, in our VEC models real gasoline prices, acting through multiple channels, were estimated to have a much stronger effect on the macroeconomy than only one oil price shock variable weighted by net import costs.

Given the implications that transport cost increases create a wider range of economic damages than previously estimated, the importance of transportation fuel reserves to mitigate supply shortfalls appears to be more important for economic stability than previously thought. Oil reserves maintained and managed by only one nation will probably be insufficient to address world oil supply shortfalls.

Kilian said in 2008 that "little would be lost by focusing on gasoline prices alone in studying the response of consumer expenditures." In fact, it may be that much has been lost by the failure to focus on transport fuel prices and spending.

2 INTRODUCTION

This paper uses the econometric methodology called vector error correction modeling (VECM) to inform a comparison of five different theories of how energy price and/or cost fluctuations cause recessions.

I. A nation that has zero or negative net oil imports will not suffer any negative consequences if there is a world oil price shock (Council of Economic Advisors, 2014). The terminology used for the operative phenomenon to be eliminated by bringing net imports to zero was the "wealth channel," in which losses of national wealth to the rest of the world oil market (via oil use aside from domestic production) are the only or predominant cause of oil-price-related economic damage.[4]

II. Variations in the price of imported oil have three different effects on the U.S. macroeconomy: (1) dislocation losses due to oil price shocks, (2) loss of GDP due to the higher monopoly price of oil, and (3) transfer of wealth in the form of monopoly rents to oil exporters (Greene, Lee, and Hopson, 2013 [hereafter GLH]). Items 1 and 2 are closely tied to the world oil price and would exist regardless of the share of oil imported. Only item 3 effects can be eliminated by reducing oil imports to zero, although such a reduction should also have the effect of lowering the world oil price.

III. The world in its entirety sees negative aggregate consequences of an oil price shock. The theory asserts that oil price and/or quantity shocks have broad, multisector economic consequences that can damage a nation's economy well beyond the wealth effect. Sectors that suffer significant losses as a result of oil price shocks, supply reductions, or both, are (1) transportation equipment (motor vehicle) sales and production, (2) housing value, and (3) leisure activities (Difiglio, 2014). Nations that specialize in motor vehicle production should suffer severe losses of the first type. Because all nations have a housing sector, any nation should suffer housing value losses. Nearly all large nations have leisure activities distant from cities, and many

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[4] The Council of Economic Advisors noted that other channels could be important, but would require a formal model. The interpretation of the model estimated was that the kind of test constructed implied the wealth channel dominated if a particular coefficient value was 1.0, while other channels dominated if it was 0.0. In four of the five tests presented in Table 3-2 of the Council of Economic Advisors document the value of the coefficient was 1.0 (Council of Economic Advisors 2014, p. 27). However, in a later estimate of effects of a 10% shock, it was concluded that "these estimates are consistent with meaningful contributions by channels beyond the wealth effect" (Council of Economic Advisors 2014, p. 28). Example channels were a supply-side channel and an uncertainty channel: "the supply-side channels associated with temporary changes in factor prices would depend on elasticities of substitution among factors of production and their shares in production, not shares of net imports, while the uncertainty channel could depend on the overall importance of energy in the economy" (Council of Economic Advisors 2014, p. 24). Variation of consumption expenditure share was used as a weighting factor for the price shock impacts occurring via the wealth channel effect, but it was not tested as a cause in and of itself. Thus, allowance for consumer benefits of transport fuel cost-reducing technological change (i.e., reduced consumer spending on transportation energy achieved by greater efficiency) was indirectly embedded in the short-run shock effects statistical model.

smaller countries benefit from significant tourism from other, often distant, countries.

IV. Significant transportation fuel price and transportation technology shocks thereby induced are a generic problem (Santini, 1984) for any balanced macroeconomy that includes significant domestic motor vehicle production (as the global economy does). Significant increases of transportation fuel price cause a temporary increase in savings in order to accomplish a newly desirable intra-sectoral substitution of transportation capital for energy.[5] This is accomplished by adoption of new capital that achieves step function (i.e., discontinuous) increases in transport system efficiency (Santini, 1986, 1992).

V. Oil price shocks are not a cause of recessions; only the monetary response to those shocks is a problem (Bernanke et al. 1997).

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[5] This effect arises from consumer (or business) expectations that gasoline prices will remain high during the period of ownership of the next vehicle, in combination with the certainty (not uncertainty) that a new, much more fuel-efficient technology is now reliable enough to realize net life-cycle savings. Because the new technology is more costly than the old, it requires a higher down payment than previously anticipated, which in turn causes either more savings or an extension of the planned accumulation period. The latter choice implies delay of purchase. If the coming technology is fairly certainly the best, but the consumer or business likes to see proof in the form of a few years of demonstrated reliability documented by experimentation (preferably by others), then this can also contribute to delay. There are no tests for these effects in this paper. In addition to the consumer's decision to delay the intended vehicle purchase and save more, another potential problem is that the ability to save may have been diminished by the increased transport costs. Maintenance of a living style would require taking money out of savings rather than putting it in. This aspect can be called the "energy squeeze" (Santini, 1985a). If, at the same time, the costs of borrowing rise (an interest rate increase), the dollar volume of auto loans sought and granted could drop significantly. In the model that we construct in this paper, a measure of consumer debt is included for the first time in our recent econometric investigations.

3 COMPETING THEORIES

3.1 GENERAL THEORETICAL ISSUES

Solow (1987) argued that the majority of long-run economic growth should be attributed to technological change. Solow's work also introduced the idea that the introduction of technology could cause macroeconomic fluctuations as significantly improved vintages of technology replaced old, inefficient, obsolete technology. Like Solow's work, the VEC modeling in this paper indirectly implies a long-run trend of technological improvement in the efficiency of motor vehicles. Real gasoline consumption increases much more slowly than real vehicle spending. Interpretation of the VEC model results and discussion related to graphs of long-run patterns of transport cost also imply that sharp pulses of investment in motor vehicles are discontinuously stimulated when consumers come to perceive large gasoline cost increases to be permanent.

Adam Smith, one of the founders of economics, included a chapter entitled "The Division of Labor is Limited by the Extent of the Market" in "The Wealth of Nations" (Smith, 1776). In 1951, George Stigler noted that this implied that reduced transport costs increase the extent of the market. In 1982, Kydland and Prescott[6] mathematically illustrated how cycles in economic growth could be induced by pulses in investment. Our analysis tests whether gasoline price shocks might induce pulses in light duty motor vehicle investment that could induce macroeconomic cycles of the type simulated by Kydland and Prescott. In 1985, the economic historian Blaug wondered why the work of several transport economists had not been incorporated into standard economic thought. Santini (1992) developed a two-region model of the process of capital for energy substitution by transportation technology; it predicted temporary increases in consumer savings in conjunction with a decrease in vehicle purchases following a major transportation fuel price shock. Once savings are accumulated, more-capital-intensive, less-fuel-consuming vehicles are purchased. The VEC model in this paper includes consumer debt, thus testing whether debt declines (savings increase) after a gasoline price shock.

Clearly, with the globalization of national economies, the importance of transportation-related technological advances has become more evident. Recent research examining 22 industrialized nations from 1962 to 1990 estimates that improvement in container ship technology was as important to growth in world trade as the reduction in trade barriers (Bernhofen et al., 2013). Induced indirect benefits were argued to be as important as the direct cost reduction effects. Nominally, this paper is about consumer demand, while many of the previously cited papers are about investments by firms. However, on weekdays, about three-quarters of vehicles used incorporate work trips (U.S. Department of Transportation, 2004).[7]

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[6] Kydlund and Prescott used ships and factories as examples of investment goods whose multi-period pulses of investment and construction might create the theoretical 8-year business cycles simulated and correlated to 118 quarters of post-WWII economic activity. Kydlund and Prescott did not address technological change.

[7] Y. Zhou of Argonne examined vehicle use on Monday through Friday. Within the 2009 National Household Transportation Survey 1-day sample of household vehicle use (conducted over several weeks), 57% of vehicles were used at least once in these 5 days. Of those that were used, 75% commuted at least one way to work.

This purpose could be counted with equal validity as investment in productive capability or as consumption. Further, the vintage modeling approach utilized by Solow is routinely applied by policy analysts evaluating the implementation of fuel-efficiency-enhancing technological change in light-duty vehicles purchased by consumers (and businesses) (Zhou and Vyas, 2014).

3.2 TRANSPORT FUEL COST VS. OIL PRICE SHOCK

One question embedded in this research is whether cost matters more to consumers than price. Another is whether the energy shocks that cause macroeconomic fluctuations are generic energy shocks averaged across (1) all energy types, (2) oil shocks, (3) gasoline shocks, or — more generally — (4) transport fuel cost shocks. A combination of the above is certainly plausible. The reference point for this discussion is the perspective that oil price shocks are the predominant cause of macroeconomic fluctuations (Hamilton, 1983, 1988; Council of Economic Advisors, 2014). Recent research by Kilian (2008) asserts that gasoline price shocks are as relevant an indicator as oil price shocks: "little would be lost by focusing on gasoline prices alone in studying the response of consumer expenditures." This seems too modest an assertion. Obviously, consumers worry primarily about gasoline expenditures, not oil prices.[8] This mild shift of emphasis from point 2 to point 3 is in the direction of transportation fuel being the primary cause rather than any fuel. This paper suggests that an additional step, from point 3 to point 4, is desirable.

Among references cited thus far, there is no discussion of system-wide engineering efficiency losses during a boom as older vintages of the capital stock (idle and little-used plants and equipment, which tend to be technologically out of date and inefficient) (Solow, 1962) are put into use. Nor is there discussion of the cyclical effects of changed vintages of the vehicle stock resulting from exhaustion of benefits from prior "pulses" introducing new technology.[9] Several years after a pulse of introduction of new, more efficient vehicular technology, the annual fleet fuel efficiency benefits disappear, while the record shows that purchasing shifts to larger vehicles in boom times when incomes rise (McManus, 2007; Kilian, 2008). Thus, the quantity of gasoline consumed per vehicle and per household rises during a boom, pushing up relative costs of operation. When this combines with a gasoline price increase, then cost increases (price times quantity) can become problematic.

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[8] It must be conceded, however, that products refined from oil were much more widely used for non-transportation applications in the first half of our sample period than the second.

[9] Inspection of Fig. 2-2 in EPA's "Fuel Economy Trends" shows that the largest year-to-year new light-duty vehicle "model year" fleet fuel economy increases occurred from 1979 to 1980 and from 2008 to 2009. The "double dip" closely spaced recession pair started in January 1980, while the "Great Recession" started in December of 2007. Model years start in September of the prior year, so the start of the 2008–2009 new vehicle fuel economy increase (September 2007) just preceded the start of the Great Recession.

3.3 WHAT CAN ECONOMETRICS TELL US?

Econometric models are inherently limited to testing relationships among a relatively few variables. A macroeconomy includes far more sectoral relationships than any single econometric test can evaluate. Accordingly, the construction of any econometric model involves prior theoretical expectations that prioritize variables to include in the model. In effect, when designed to reveal information about a macroeconomy, any econometric model is a submodel, or a gross simplification of that macroeconomy. Thus, econometrics only allows a limited investigation of relationships of some of the many variables that are included in large models of the macroeconomies of nations, regions, or the world. Econometrics *can* reveal information in support of sector-specific subroutines in a macromodel, as a check of overall behavior of the key aggregate variables in a macromodel, or some of both.

This paper presents a new econometric base model that uses a statistical approach (vector error correction, VEC) that has not been used in models constructed by most other authors (Table 3). It includes sensitivity of results to inclusion of one additional variable (one of five tested) in the simple "wealth effect" model constructed for the Council of Economic Advisors. The Council of Economic Advisors model and all but a few recent others discussed used the econometric methods vector autoregression (VAR), or autoregressive distributed lag.[10]

The new base model in this paper represents an evolution in our thinking, while taking advantage of the following:

A. The slow evolution of econometric method and theory into practice (Engle and Granger, 1987; Hamilton, 1994)

B. Prior theoretical models (Fisher, 1933; Santini, 1985a, 1992)

C. Prior econometric tests (Hamilton, 1983, 1988, 2009; Santini, 1987; Barsky and Kilian, 2001; Santini and Poyer, 2008a, 2008b, 2014; Kilian, 2008; Edelstein and Kilian, 2009), and

D. Inspiration from current thinking about the causes of the Great Recession (Eggertsson and Krugman, 2012; Hamilton, 2012; Mian and Sufi, 2014; Sexton et al., 2012; Stock and Watson, 2012; Santini and Poyer, 2014).

A now well-understood problem in scientific inquiry is that theory and empirical testing are inextricably intertwined (Kuhn, 1970, 2012). Although science does often inadvertently discover something that is not being searched for, odds are slim. If a variable that represents a good measure of a theoretical process is not included in an econometric model, it is doubtful that

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[10] Greene, Lee and Hopson draw from econometric models, but do not construct one themselves.

TABLE 3 Comparison of Several Studies with Regard to Length of Price Change Impacts Examined

Study (or studies) Descriptors	Method	Type of Gasoline or Oil Price Increase (time period)		
		Transitory or Short Run (Months, Quarters)	Permanent or Long Run (Years)	Very Long Run (Decades)
All of the above (Council of Economic Advisors, 2014) [I][a]	Distributed lag; graphs/case studies/logic	Six quarters		
OPEC and U.S. oil dependence 1970–2010 (Greene, Lee, and Hopson, 2012) [II]	Mathematical model; charts/graphs/case studies/logic	A year, no months or quarters	Long-run, but time not defined	
Oil, world economic growth and oil reserves (Difiglio, 2014) [III]	Experience; case studies, graphs; deductive logic	0–5 months	2–3 years	
Transportation costs and economic growth fluctuations (Santini, 1984–1989, 1992, 1994) [IV]	Granger causality; mathematical model; graphs/case studies/logic		Statistical analyses, 2–3 years	Math model, logic
Money or oil shocks cause recessions? (Bernanke et al., 1997) [V]	Vector autoregression (VAR); Graphs/case studies/logic	Months	4 years (48 months)	
This study (finance and gasoline cause recessions)	Vector error correction (VEC)	Quarters	5 years (20 quarters)	Cointegration estimate, test
Oil price shocks cause recessions (Hamilton, 1983, 1988, 2009, 2012)	Vector autoregression (VAR); graphs/case studies/logic	Quarters	Up to a few years	
Gasoline price causes vehicle output (Kilian, 2008)	Vector autoregression (VAR); graphs/case studies/logic	12–18 months	2–4 years	
Gasoline price causes vehicle output (Ramey and Vine, 2010)	Vector autoregression (VAR); graphs/case studies/logic	Months	4 years (48 months)	
Vehicle output causes other GDP (Santini and Poyer, 2014)	Vector error correction (VEC)	4 quarters		Cointegration estimate, test
World oil markets, U.S. financial and GDP (Oladosu, 2015)	Vector error correction (VEC)	1–2 quarters	5 years (20 quarters)	Cointegration estimate, test

[a]   See Chapter 2 for an explanation of each of the theories that correspond to these roman numerals.

the model will result in a discovery of the relationship that the variable represents.[11] Thus, results depend very heavily on the variables included in, and excluded from, any econometric model. Generally, the analyst is only able to translate the econometric information in terms of the original theory that led to the test, whether or not the analyst realizes this. Theories evolve slowly and are resistant to alteration as a result of empirical information. According to Mankiw (1990), there were several lines of emerging macroeconomic theory that could prove productive at about the present time (i.e., 2015). The two then-emerging theoretical structures most directly applicable to this paper were the "real business cycle" theory and the "sectoral shifts" theory. Perhaps none of the theories Mankiw mentioned were exactly on track; perhaps one of them simply requires tweaking. We attempt to interpret our econometric results in terms of the five explicit theories being compared, and in terms of these two generic macroeconomic theories, as we understand them.

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[11] If construction of a good summary variable for a correct relationship is impossible, econometrics will never completely succeed. In particular, there may not be any generalizable measure of technical change from one major (transportation) technology shock to another, requiring that analyses be descriptive case studies rather than econometric investigations.

4 METHODOLOGICAL ISSUES

4.1 PRICE SHOCKS: TRANSITORY, SUSTAINED, AND PERMANENT

In 1981, Tatom distinguished between transitory and permanent real energy price changes. For the purposes of this paper, a transitory real energy price shock is one that subsides in a matter of several quarters, a sustained shock is one where the real energy price level is significantly different from trend for 2 years or more, and a permanent shock is one where the real energy price level is different from trend for more than 5 years. The OIRFs plotted in this report show the effect of a permanent shock of 1% over 5 years (20 quarters). Tatom asserted in 1981 that such a permanent increase in real energy price, with no change in technology or resource use, permanently reduces national output. The VEC results simulated here are consistent with Tatom's argument, but the facts at the time were not.[12]

4.2 ELASTICITY VS. IMPULSE RESPONSES: SHORT RUN, LONG RUN, AND VERY LONG RUN

Economists often discuss short-run and long-run elasticity, but they almost always neglect to specify the time interval for which each term is applied. GLH are partially specific in what they mean, specifying a year to be short-run; a year is far too long a period in which to anticipate and prevent recessions or to make decisions about a petroleum reserve release. Difiglio (2014) provides no time specification in relation to the literature discussion of short-run elasticity; however, it is clear that he is not talking about a year, since the topic he refers to is management of petroleum reserves. His discussion involves the consequences of hesitance to release petroleum reserves; he discusses initial month and 5-month releases, while noting that International Energy Agency (IEA) reserves are intended to last only 90 days. Thus, for purposes of petroleum reserve release policy, one must think of the short run as considerably less than 1 year.

As is the case with our research here, most VAR, Granger-causality, and distributed-lag based research of the effect of oil price shocks has been based on quarterly data, and includes examinations of quarterly effects. More recently, monthly data has been used. The more recent VAR analyses, as well as our VEC analysis, plot and compare a time profile of response to shocks, which is now commonly called an impulse response. Short- and long-run elasticity discussions are generally absent from these papers, because information is presented on responses that differ quarter by quarter, or month by month.

For this study, we carefully examine three different periods of time. To overlap with Difiglio's choice, short run will be the first two quarters of activity after a hypothetical permanent (5-year) shock to a variable in our system of dynamic equations. Long run will be 5 years (the full 20 quarters of our impulse response plots), which is similar to several of the

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[12] Real prices steadily declined after 1981 (see Figure 2), automotive technology was changing rapidly (EPA, 2013, 2015), and resource use (gasoline) was dropping (see footnote 2).

studies we examined (Table 3). As Figure 9 illustrates, there were no periods where real gasoline or oil prices remained at an elevated and consistent level for 5 years: however, elevated, but unstable prices did endure for that length of time. Finally, we will also think in terms of the very long run, defined by a finding of cointegration between two variables. The statistically linked trends that are defined by the cointegration equation over the full sample period are called the very long run. In the very long run, the major price shocks of the 1970s reverted toward prior levels. Recent declines in prices (not plotted) raise the question of whether this reversion will be repeated.
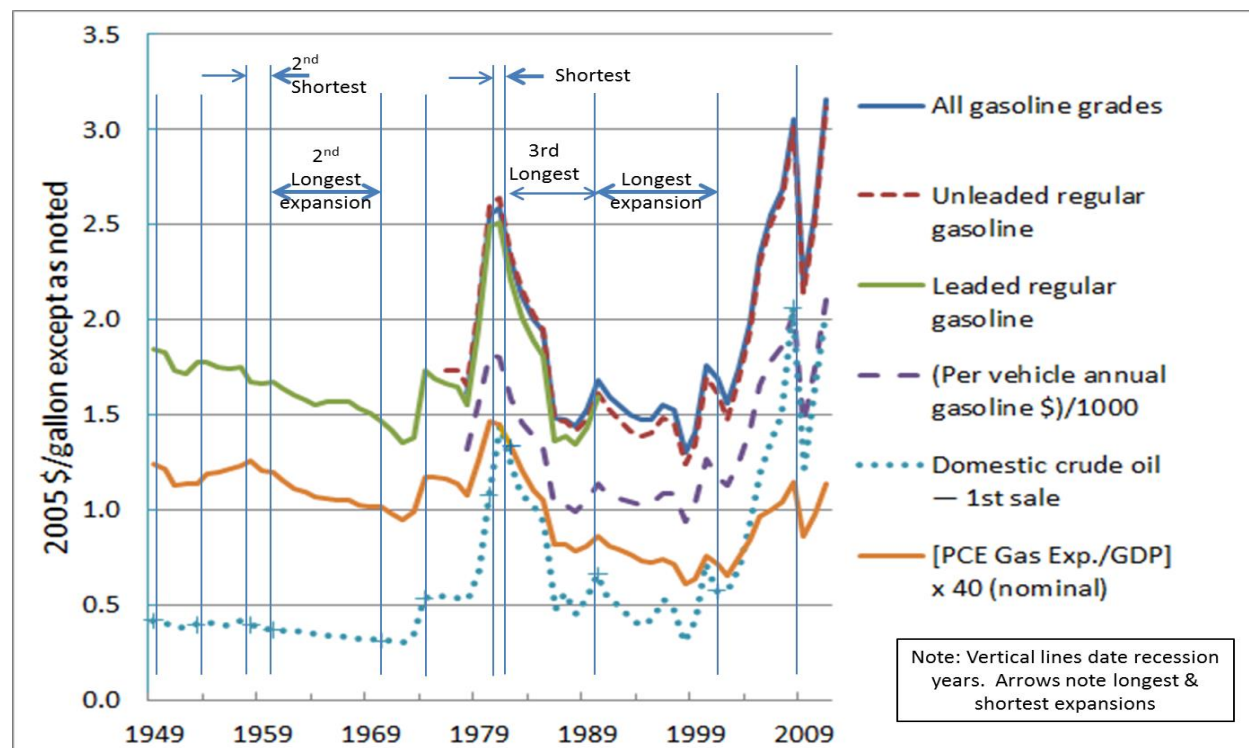
FIGURE 9 Patterns of Gasoline and Oil Prices and Expenditure Shares from 1949 to 2011

4.3 PRICE RESPONSE VS. EMBEDDED TECHNOLOGICAL CHANGE

As we will see, if we choose to define the very long run as we have, the response of gasoline consumption to gasoline price increases is estimated to be elastic. Because conventional wisdom is that this response is inelastic, this raises the question of whether or not the very-long-run reduction of gasoline consumption is due only to responses to gasoline prices, or is a result of a political-economic system well designed to implement technological advances in anticipation of future needs, well before price signals make those needs evident. Is there a scientific-engineering efficiency-enhancing tendency built into the U.S. political system? Perhaps price signals only accelerate changes that science and engineering have previously made available. Is the stronger signal of need engineering efficiency or economic efficiency? Santini's 1987 and

1994 estimates based on yearly values implied that the former is more important than the latter. How do our VEC results compare to those Granger-causality tests?

4.4 DECOMPOSING EFFECTS OF CARTEL SUPPLY FLUCTUATIONS

As a cartel, OPEC intentionally restricts oil supply on behalf of its members, in order to enjoy the benefits of a higher oil price. The OPEC cartel members do not always produce the amount of oil specified in their quota, however. In peacetime, members often "cheat" on their quotas, producing more than officially allowed. Wars or political choices have frequently caused production to drop below allowed levels. War is not part of the theory of behavior of cartels (Bannock et al., 1992). However, major restrictions of collective OPEC output have very frequently been associated with wars or armed conflicts. Given the history of the Middle East, prevention of such wars and armed conflicts is unlikely. The theory of cartel behavior (Bannock et al., 1992) says that cartels are unstable, tending to be subject to large, long-term swings in prices. Intermittent price declines following successes in restraining production result from member producers cheating on quotas, or from successful development of substitutes by consumers. In the case of OPEC, wars have been as important in achieving production reductions as has strict cooperation by members.

The Council of Economic Advisors developed a single formula for theoretical damages arising from importing oil. According to the formula, the greater the United States' dependence on imported oil, as expressed by share of oil imported, the more damaging a price shock would be to the economy. Only quarterly price shock effects were tested.

The Council of Economic Advisors wealth effect (actually, a weighted dislocation/shock effect that combines price change, price level, quantity imported, and GDP) definition is quite different from that developed by GLH. GLH created estimates of damage to the U.S. economy from the loss of "wealth" (actually, yearly income) to nations supplying oil to the United States. The assumption is that the OPEC cartel exerts market power by restricting production and thereby increasing price above the level that would be realized with perfect competition. They estimate the price that would theoretically exist with perfect competition and assign losses arising from the increment in price caused by OPEC supply restrictions. GLH treat price shock dislocations separately. They are not part of their wealth effect.

Because the short-run elasticity of demand is low, rather small restrictions in world supply can cause large increases in world oil price (Difiglio, 2014). From the Difiglio world market perspective, fluctuations in world oil price cause fluctuations in world output. A properly operated international petroleum reserve is desirable to reduce fluctuations in world oil price so that world economic growth will be more stable. Oladosu (2015) empirically verifies that release of Organization for Economic Co-Operation and Development (OECD) petroleum stocks increases global consumption and reduces world oil price. Wealth effect transfers among nations are not an issue because they should net out at a world level. There is no attempt to isolate declines in world economic output attributable to price change versus price level. Difiglio discusses how individual nations might suffer as a consequence of a rise in oil prices. One emphasis is on the decline in motor vehicle sales and output. Another effect is a decline in equity

of houses due to higher costs of transport to locations far from jobs. From the Difiglio perspective, oil price changes can be particularly damaging to nations that manufacture a large number of motor vehicles; they can be also be damaging to any nation since all nations have a housing market. The damages are all transportation related. There is no financial sector in the discussion.

Difiglio assumes that world oil price increases are caused by reductions in world supply. Like GLH, he is primarily concerned with oil availability variations from OPEC members. Amounts of world oil supply reduction, often caused by conflicts among and within Middle Eastern nations, are discussed thoroughly. Thus, he discusses both reduction in oil quantity and increase in price as precursors of world economic decline occurring over a 2 to 3-year period.

4.5 INDUCED TRANSPORT TECHNOLOGY TRANSITIONS: ACCELERATED CAPITAL FOR ENERGY SUBSTITUTIONS

Figure 9 illustrates that the volatility of real oil and gasoline prices was greater after 1972 than before. During the pre-1972 period, the United States produced a much larger share of world output than after. The Texas Railroad Commission regulated output (Difiglio, 2014) in the Saudi Arabia of the time, Texas. While this lasted, real oil prices were relatively stable and steadily declined. Although prices were relatively stable, Hamilton's initial 1983 research implied a link between energy prices (oil and coal were examined) and macroeconomic activity in the earlier period, as well as the later period. After 1972, the U.S. share of world oil production generally declined and OPEC became the dominant organization attempting to manipulate prices.

Although real gasoline and oil prices declined relatively steadily from 1949 to 1972, the share of consumer spending (orange line) on gasoline did not (Figure 9). This particular case shows a notable change in gasoline expenditure share of GDP in the 6-year period from 1950 to 1958. An increase in gasoline consumption was the key factor in this case. This period has been described as the Great Horsepower Race. This is an interesting case because the gasoline spending GDP share increase was clearly not related to price. The Suez crisis in the Middle East restricted Suez Canal oil flows in 1958, the end year of this gasoline spending share run-up. After 1958, domestic automakers introduced smaller cars as a result of the oil crisis and successful competition from the imported Volkswagen Beetle. The gasoline spending share increase was followed by two unusually closely spaced recessions as the auto industry adjusted its technology mix.

Two separate, even more significant multi-year share increases (see Figures 9–11), occurred during the OPEC era. These were followed by automotive technology transitions (EPA, 2013) and severe recessions.

Leading into the Great Recession, from 2002 to 2008, the gasoline expenditure share of personal consumption expenditure rose by ~75%, with a Δ of ~1.7% (Figure 10). The gasoline expenditure share from 1969 to 1986 is plotted in Figure 11. From 1972 to 1980, gasoline expenditure share rose by ~53% with an increment of about 2%. At the end of this expenditure
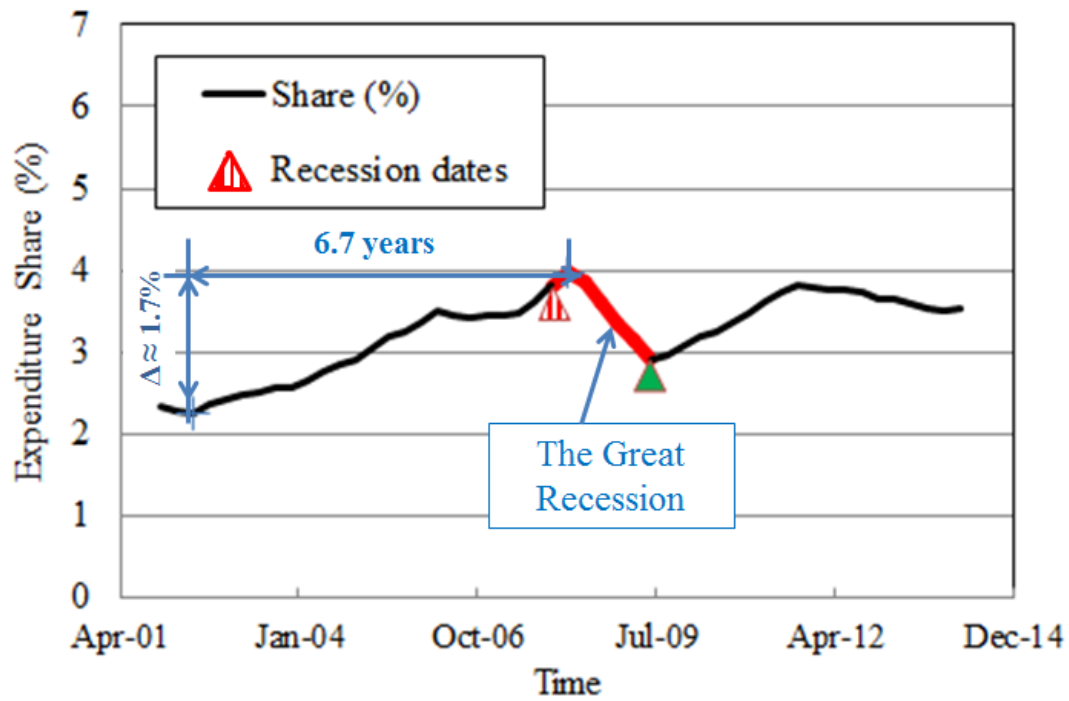
FIGURE 10 Very-Long-Run Change in Gasoline Expenditure Share of Personal Consumption vs. Great Recession
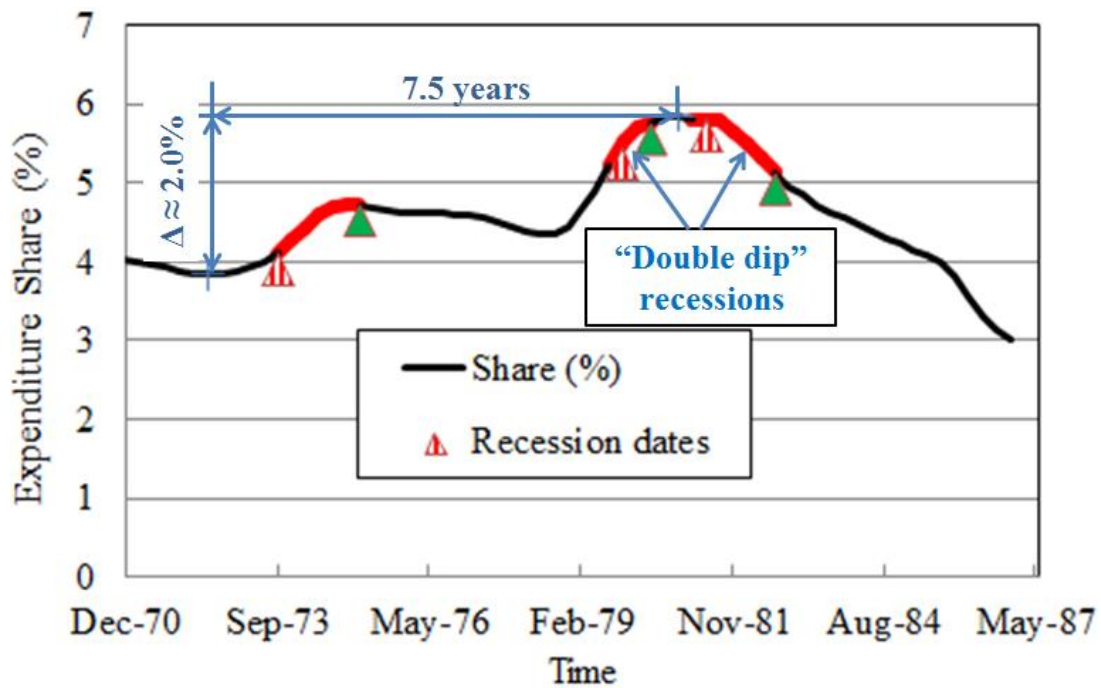
FIGURE 11 Very-Long-Run Change in Gasoline Expenditure Share Leading into the 1980–1982 Double-Dip Recessions

share increase, a "double-dip" pair of closely spaced recessions occurred. Although the Great Recession was worse because of financial problems in the housing sector, about the same cumulative gasoline expenditure rise occurred as before the double dip.

These patterns of multiple-year (very-long-run) gasoline expenditure share increases followed by unusual macroeconomic difficulties are consistent with the "energy squeeze" perspective suggested by Santini (1985a). The efficiency-enhancing vehicle adaptations that followed each study period's multiyear gasoline spending share increases are consistent with Santini's description of fuel cost shocks and technological change in transportation (Santini, 1984) and a follow-up quantitative model of long-run capital for energy substitution (Santini, 1986, 1992). This discussion illustrates that the Great Recession fits the description and model. Each of these periods of rising expenditure shares was very long run by the definition used here (more than 5 years). These more-severe recessions or recession pairs end a long-run sustained increase in consumer spending share for transportation fuels. However, not all recessions occur at the end of such unsustainable long-run spending share increases, nor are all recessions severe. For remaining recessions, relatively short-run transportation fuel cost increases also play a role in many cases.

For this study, the primary goal was to develop an understanding of the contribution of transportation fuel cost changes to short-run macroeconomic performance rather than to address the long-run technology transitions discussed in this section. The difference of the 1952–1958 case (consumption increase causing share increase) from the 1972–1980 and 2002–2008 gasoline spending share increase cases (real gasoline price causing the share increase) suggests careful investigation of price and quantity separately and combined may be desirable to determine whether price of fuel or cost of operation (spending) is a more important variable in the consumer decisions that ultimately affect the macroeconomy.

The energy price/cost shock reaction is known to be fundamentally different in the short and long-run, as noted in the Council of Economic Advisors 2014 report (p. 23):

> "Although capital and labor substitute for energy in the long run, in the short run they can be complements in production because of fixed technologies, so higher energy costs can result in layoffs in energy-intensive firms and industries."

The VEC technique is chosen because of its theoretical superiority in sorting out these different short-run and long-run effects. The fundamental short-run question is whether or not transportation fuel cost shocks are the primary cause of recessions, or whether high cost levels are also very important. We examine rpgas and real gas spending (a quantity surrogate) separately here (see Tables 4 and 5). Kilian (2008) and Edelstein and Kilian (2009) have *weighted* real gasoline price increases by consumer expenditure share, whereas the Council of Economic Advisors uses a net-oil-import-spending-share-weighted oil price percentage increase. None of the cited analyses have examined the influence of changes of consumer expenditure share (or net oil import share) itself, nor have they cited examined quantity effects. Santini did both previously, with annual data, for the period from 1889 to 1985 (Santini, 1987). Energy spending and energy quantity, each estimated alone, had more predictive value for real GDP and unemployment rate than did energy price alone.

TABLE 4 Raw Variable Definitions, Units, and Source

Variable	Definition	Units	Source
DGOERC1	Gasoline and Other Energy Goods	Billions of dollars	Bureau of Economic Analysis
DGOERG3	Price Index for Gasoline and Other Energy Goods	Index Number, 2009 = 100	Bureau of Economic Analysis
DPCERC1	Personal Consumption Expenditures	Billions of dollars	Bureau of Economic Analysis
DPCERG3	Price Index for Personal Consumption Expenditures	Index Number, 2009 = 100	Bureau of Economic Analysis
A191RC1	Gross Domestic Product	Billions of dollars	Bureau of Economic Analysis
B191RG3	Price Index for Gross Domestic Product	Index Number, 2009 = 100	Bureau of Economic Analysis
cmdebt	Households and Nonprofit Organizations; Credit Market Instruments; Liability	Billions of dollars	Federal Reserve Economic Data
cpiaucsl	Consumer Price Index for All Urban Consumers: All Items	Index Number 1982–1984 = 100	Federal Reserve Economic Data
oehrenwbshno	Households; Owners' Equity in Real Estate	Billions of dollars	Federal Reserve Economic Data
DMOTRC1	Motor Vehicle and Parts Expenditures	Billions of dollars	Bureau of Economic Analysis
DMOTRG3	Price Index for Motor Vehicle and Parts	Index Number, 2009 = 100	Bureau of Economic Analysis

TABLE 5 Model Variables and Definitions

Model Variables	Definitions
lnequity	*Real equity*—Natural logs: ratio of nominal owners' equity to the consumer price index for all urban consumers (ln[oehrenwbshno] – ln[cpiaucsl])
lnrpgas	*Real Price of Gasoline*—Natural logs: ratio of the nominal gasoline and other energy goods price index to the personal consumption expenditure price index (ln[DGOERG3] – ln[DPCERG3])
lnrcmdebt	*Real consumer Debt*—natural logs: ratio of nominal households' credit market instruments liability to the consumer price index for all urban consumers (ln[cmdebt] – ln[cpiaucsl])
lnRMVE	*Real Motor Vehicle Expenditure*—Natural logs: ratio of the nominal motor vehicle and parts expenditures to the price index for motor vehicles and parts (ln[DMOTRC1] – ln[DMOTRG3])

TABLE 5 (Cont.)

Model Variables	Definitions
lngas	*Real Gasoline and Other Goods Spending*—Natural logs: ratio of nominal gasoline and other energy goods expenditure to the price index for gasoline and other energy goods (ln[DGOERC1] – ln[DGOERG3])
lnrGDP	*Real GDP*—Natural logs: Ratio of nominal GDP to GDP price index (ln[A191RC1] – ln[B191RG3])
oilshrp3	Council of Economic Advisors composite measure of a "wealth channel" variable weighting oil price changes (West Texas Intermediate Oil) by share of net imported oil spending in GDP.

4.6 PRICE AND QUANTITY

As the closing of the prior section illustrates, a general question in this investigation is whether an accurate depiction of macroeconomic effects of the oil market on the macroeconomy can be measured via price effects alone. Most of the literature implicitly assumes that only oil prices matter. Quantity supplied is not examined. In an engineering sense, quantities of inputs are needed to produce quantities of outputs. For a fixed stock of oil using fixed capital equipment, a reduction in quantity of oil supplied means that some equipment cannot be used, thus reducing national output. In the econometric tests in this paper, a surrogate for quantity of gasoline used for personal consumption is included (lngas, Table 5).

A price shock may arise because of either a positive shock to quantity demanded or a negative shock to quantity supplied. An ability to inject supply can mitigate price shocks and allow productive equipment (vehicles) to continue in operation, thereby mitigating macroeconomic damage. For purposes of closing short-run gaps between gasoline demand and supply, a transportation fuel reserve would be theoretically ideal, if increases in transport cost are one of the fundamental causes of many mild and all severe macroeconomic contractions. Should demand exceed supply due to cold winters[13] or boom-induced expansion of use of inefficient vehicles, then a reserve can fill the demand-induced gap until the winter is over or consumers can shift to use of more efficient vehicles. Should supply fall short of demand due to a war in the Middle East or a successful effort by OPEC to restrain supplies, then a transport fuel reserve could provide some cushion while consumers adjust.[14] Adjustments of new vehicle efficiency by automakers and consumers take much more time and can have only a small effect on the fleet's inherent fuel efficiency in the short run.

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[13] Bloesch and Gourio (2015) note that weather data series are ill suited to testing the theory that heating fuel demand increases due to cold winters are an important factor reducing economic growth. Cold temperatures also reduce the per-mile operating efficiency of transportation equipment.

[14] Adjustment of the use of large vs. small existing vehicles may have a significant effect, but available data are inadequate to estimate these effects (Energy Information Administration, 2015, Table 1.8).

According to either the Council of Economic Advisors, or GLH, if the quantity of imports goes to zero, the wealth effect disappears. Our base VEC model does not include any variable designed to address the wealth effect, but the model is designed to accurately isolate the "dislocation losses" (what most other authors call shock effects) and price-level effects. In the VEC model, the price-level effect can cause an immediate effect on macroeconomic growth. Both a dislocation (price change) effect and price-level effect can cause short-run damages. By mitigating price increases for transportation fuels, a transportation fuel reserve can reduce the theoretical price-induced damages estimated in these two models. GLH use annual data and define the short run as a year. For purposes of mitigating an oil price shock, Difiglio (2014) clearly believes that a year is far too long to react. Our VEC modeling addresses both contemporaneous price-level effects and near-term lagged price shock effects over a period of two quarters. Thus, the estimates are tailored to determination of short-run dislocation (shock; price change) and price-level effects.

If the Council of Economic Advisers' (2014) theory accounts for the vast majority of U.S. macroeconomic problems when world oil prices increase, then if the United States was able to eliminate its oil imports, the U.S. economy would be able to run smoothly thereafter.[15] Implicitly, this theory suggests that the United States moved into historically atypical circumstances when it became a major importer of oil after domestic oil production peaked in the 1960s.[16] According to this theory, the recent strong revival of domestic oil production therefore has the potential to eliminate this unique post-1972 problem in U.S. history. If the theory that the wealth effect is dominant is correct, then it is possible to assert that the United States will have very little self-interest in contributing to maintenance of a world petroleum reserve to address fluctuations in supply of world oil, should it reduce U.S. net oil imports to zero or less.

4.7 PHILOSOPHY OF CAUSE

The concept of Granger causality is that the past causes the present. As a result of the conceptual constraint that a contemporaneous correlation cannot support an opinion for direction of cause, this meant that high contemporaneous correlations between energy variable changes and the macroeconomy (Santini, 1987, 1994) could not be used to support the argument that the cause was from energy to macroeconomy. That work was based on annual data, but did go back to 1889. All other cited studies examine post-WWII periods.

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[15] The Council of Economic Advisors report (Council of Economic Advisors, 2014) noted that if the variable alpha in the model specification was one and the net oil import share zero "oil price shocks would have no effect on GDP growth." When alpha is one, the specification amounted to a weighted oil price shock, in which the weight was the "expenditure share of net petroleum imports […] the product of net barrels of petroleum imports times the price per barrel, divided by GDP." In four of five alternative estimates of the specified model, the value of alpha presented was one. It was noted elsewhere in the Council of Economic Advisors report that other "channels" could be important (Council of Economic Advisors, 2014, p. 24), but would require a formal model. The report touted potential benefits of domestic policies supporting technologies intended to reduce oil consumption and increase domestic production. The emphasis was on the benefits of achieving import independence.

[16] In contrast, Santini's theory is explicitly generic, asserting that transport cost and technology implementation shocks have caused macroeconomic fluctuations in the United States since its founding (Santini, 1984–1989).

Hamilton's 1983 analysis, and many that followed, used post-WWII quarterly data. Recent analyses have used monthly data. The finer-grained detail can reveal what is happening within a year, even holding to the Granger causality conceptual constraint. Hamilton found that a GDP effect peaked about three quarters after an oil price shock. Recent papers by Kilian (2008), Edelstein and Kilian (2009), and Ramey and Vine (2010) have shown a much more prompt decline in vehicle sales or output following a gasoline price increase.

In our work, we posit a two-step causal sequence, from (1) real gasoline price (and/or real spending) to real motor vehicle sales, then from (2) real motor vehicle sales to real GDP. Because the overall process takes a year to unfold, the underlying two steps have to occur in less than a year. We allowed ourselves to test for only two quarters of lags, rather than four. If the two-step hypothesis is correct, this should provide an adequate estimate.[17]

A major conceptual change in the kind of cause for VEC versus VAR is that present levels can cause changes in the immediately following period in the VEC. The VEC model approximately allows the present to cause the present. Admittedly, the two variables in question are not quite contemporaneous. A price level at a given point may cause a change from that point in time to another future point in time. Temporally, these two variables tested in the VEC (level and rate of change) are closer in time than would be a pair of rate of change estimates in a VAR model.

In fact, perceptions of the future can cause present actions. In economics, this is called "rational expectations." Many authors discuss uncertainty as a reason for purchase delay. However, in the event of a major unanticipated price increase that consumers expect to be permanent, certainty may be a factor. In the event of higher transportation fuel prices, the expectation of their permanence causes a change in priority among available vehicle technologies. More expensive (more capital intensive) vehicles that reduce fuel use (capital for energy substitution) become desirable. Santini's model (1986, 1992) predicts that consumers will delay purchases to build up larger than previously anticipated initial cash outlays for the next vehicle purchase. This is a change of behavior due to changed future expectations for fuel prices, along with certainty that an alternative purchase decision has become desirable. Other factors may also influence purchase delay, including uncertainty. However, this illustrates that certainty about desirability of technical change can also lead to purchase delay.[18]

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[17] Since only annual data is available before WWII, these tests are not possible.

[18] The recommended tests and confirming studies for the general theory are for the full history of the United States. Such tests examine points in time at which it becomes relatively certain that a strong acceleration of slowly evolving disruptive switches (Christensen, 2003) to new transportation technologies have become desirable, making many prior investments and much production capacity obsolete (see Santini, 1988, 1989). When improvements in transport efficiency occur in a pulse, then a new real business cycle involving creative destruction (Schumpeter, 1939) of productive capacity for the replaced technologies begins. Although the grand sweep of technological revolutions is recognized (Gordon, 2012), non-engineers do not consider the importance of what some might think of as interim "tweaks." In the case of various severe recessions, interim adjustments to the recognized grand technology are important. When adjustments become sweeping change, the creative destruction is much more pervasive and its consequences are much worse, leading to depressions or severe multi-year growth slowdowns (Santini, 1985b, 1985c). An incomplete list of transportation technologies would be longer than that included by Gordon in his broader list of major transformative technology examples: (1) wind to steam in maritime transport; (2) horse-drawn wagon to canal boat; (3) horse-drawn wagon to automobile; (4) dirt

An incorrect prior assumption about cause also has impeded progress in this area of research. The standard assumption was that vehicle sales are particularly elastic with respect to changes in income. Thus, a positive contemporaneous correlation between a change in income (or GDP) and change in vehicle sales was intuitively perceived to be caused by the change in GDP causing the change in vehicle sales. Our investigation of the relationship between these two variables reveals what is called "bi-directional" causality. Both directions of cause exist.[19] However, the temporal sequence of changes (Santini and Poyer, 2013) shows that a short-run vehicle sales collapse occurs first after a gasoline price shock, followed by a delayed decline in total national employment. This pattern also shows up in the results presented in this report. The dominant direction of cause in a recession appears to be from gasoline price to vehicle sales to macroeconomic output; however, there now appears to be a side effect of the gasoline price change that goes directly to macroeconomic output, though with a longer delay. The important incremental contribution of the model constructed here is the insight that the abrupt change in vehicle sales probably signals activation of more channels of long-term change in aggregate economic activity associated with restructuring of land values and optimal locations for investment in residential and business structures. The behavior of the consumer debt variable indicates that relatively sudden changes of long-term expectations disturb the flow of investment funds through altered savings and lending patterns.

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roads to paved roads; (5) canal to rails first using steam engines, then diesel-electric; (6) for railroad and ship steam engines, compounding and triple compounding; (7) for internal combustion engines (a) compression ratio increases enabled by octane increases, or (b) turbocharging of engines using either diesel or gasoline fuel; (8) refined petroleum product improvements by (a) changes of additives such as tetraethyl lead or methyl tertiary butyl ether, or (b) production processes allowing octane increases enabling improved internal combustion engine efficiency and power, such as the Burton process; (9) electrification of urban railways; and (10) front wheel unibody automobiles replacing those with body-on-frame rear-wheel drive. Some of these switches were adopted as a technological shock to the system caused restructuring of multiple niche market technologies at their tipping point.

[19] A 1951 discussion of economic history illustrates the idea that a direction of causality (in transportation) may be ignored or understated if the applicable theory asserts that it is in a particular direction. In "The Division of Labor is Limited by the Extent of the Market," George Stigler discussed that concept—one that Adam Smith had introduced in "The Wealth of Nations" (1776); Stigler discussed the 1800s benefits to Britain of a very large market with a great deal of specialization. Stigler noted that "reductions of transportation costs are a major way of increasing the extent of the market." He later stated that Britain, "As the largest economy in the world […] could carry specialization further than any other country, especially those 'general specialties' (like railroads, shipping, banking, etc.)." Perhaps Stigler had cause and effect backward; perhaps he simply understated the transportation cost reduction benefits to the market. A sound, technologically advanced transportation network and banking system can be argued to be foundational to the establishment of a large market with significant division of labor. Of course, the causality probably was bi-directional, as we have found for motor vehicles and macro activity. The empirical models discussed here include a key function managed by the banking system (issuance of debt and management of savings) and the part of the transportation system used by labor to support production and consumption of goods (commuting and purchasing). Stigler's theoretical discussion focused on business investment decisions in transportation services, rather than consumer decisions. Although the empirical work here is about consumers, much of the supporting theory is generic, applying either to business or consumer spending choices. The empirical disconnect in this paper (personal consumption but not business investment) should be addressed at a future time. The implicit assumption here is that the financial pressures on consumers and businesses from rising transport costs are similar, as are the decision processes about subsequent transportation spending. Kilian (2008) noted a strong case for the "operating cost channel" pushing new vehicle spending down, particularly for light trucks, which are less fuel efficient than cars. He also documented the sharp declines that were seen in new heavy commercial truck spending. Consistent with Difiglio's contention that leisure losses are important, Kilian also documented declines in sales of recreational vehicles, pleasure boats, and pleasure aircraft.

5 MODEL CONSTRUCTION AND INTERPRETATION

5.1 ENDOGENOUS VS. EXOGENOUS DETERMINATION: OIL OR GASOLINE PRICE IN PARTICULAR

A major question in these experiments is whether or not oil or gasoline price shocks are endogenous or exogenous to the United States. An endogenous variable is one "whose value is determined by other variables in the system" (Bannock et al. 1992). An exogenous variable is "one whose value is not determined within the set of equations" (Bannock et al. 1992). The degree of determination within and outside the system can be measured by the R^2 value. Also called the coefficient of determination, this is a statistical measure of how well the regression line approximates the real data points. A value of zero means no relationship whatsoever; a value of one indicates the best relationship attainable. The adjusted R^2 is regarded as a better measure. On this basis, the model results for the error correction equations (presented later) indicate that real gasoline spending is very poorly explained, and that nearly all of its variation is outside the system of equations. The alternative transport fuel cost variables are also poorly explained by the model's error correction equations. On this basis, treatment of these variables as exogenous to the system is valid. This result is consistent with prior thinking that energy price and quantity are drivers of the economy in the short run, although not driven by the economy in that time frame.

In an analysis of the world market for crude oil, Kilian and Murphy obtain a relatively high estimate of the short-run oil price elasticity of gasoline demand: -0.26. They use a simultaneous equation model that "explicitly introduces an income-feedback variable (shipping index) that conveys a macroeconomic impact on oil demand following an oil price shock" (Kilian and Murphy, 2014). Many other estimates of short- and long-run elasticity have been based on single nations (often the United States) and have not considered income or other feedback effects (Difiglio, 2014). However, it is possible that both approaches are valid. The ability of consumer demand in any single nation to affect the world oil or transportation fuel price may be limited and, for that nation, world transport fuel prices could legitimately be treated as exogenous. Collectively, however, the cumulative consumer income responses of all nations in the world market could cause an increase in elasticity not seen in econometric modeling of any single nation. The dynamic VEC model here includes feedback effects of real GDP and other variables in the United States. A recent VEC model of the U.S. economy (Oladosu, 2015) is consistent with this interpretation. World demand is estimated to be a strong positive predictor of West Texas Intermediate (WTI) oil price over 5 years, but U.S. GDP has a very mild effect on WTI by comparison, with the influence even turning negative in the second half of the 5-year period.

Granger causality tests from the 1980s (Santini, 1987, 1994) used past values of the dependent variable in combination with past values of the independent variable. In the case of interest here, if we were stuck with the Granger causality rules of the 1980s and wanted to determine whether any of our six base model variables had an influence on gasoline price, we would run five different two-variable models. Each would have first differences of past values of gasoline price. Five separate Granger causality models, one for each of the variables of interest, would be run and each examined separately to determine whether a significant effect existed. In

2015, with the VEC method and more data, it is possible to run all variables simultaneously in the same dynamic model, and to separately examine the impulse response functions for each of the five variables on gasoline price. With regard to system-wide endogeneity, one could argue that if any of the six variables had a significant influence on gasoline price, then gasoline price would be endogenous. However, what if the only variable that has an influence on gasoline price is gasoline itself? In terms of the meaning used by Kilian and Murphy, an influence from other variables is what determines system endogeneity. We would then call gasoline price endogenous to the system only if at least one other variable has a significant influence on it.

In the models estimated here, for real gasoline price, only home equity changes lagged one quarter have a significant effect; the goodness of fit of the real gasoline price error correction equation is poorest of all equations. For the Council of Economic Advisors world oil price wealth effect variable, there are no cases where there is a significant influence from another variable in either the short-run (shock) or long-run (levels) tests. To the extent that world oil price effects have been tested here, they are exogenous to the United States. As noted, this is consistent with findings of Oladosu. Deductively, because the United States does not influence the world oil price, despite being the largest consumer of oil in the world, it is doubtful that any other single nation could alone influence the world oil price. Only collective, cooperative actions could do so. Oladosu (2015) estimates that such collective actions (OECD stock releases) do have desired effects.

In general, we track the dynamic effects in both directions, reporting key results of interest. A top priority was to demonstrate that the gasoline price to real GDP effects previously estimated in simpler models actually involve intermediate steps, where gasoline price first affects other variables and those variables in turn affect real GDP.

5.2 CAUSAL ORDERING

The VEC model can develop different results depending on the presumed causal ordering used in the setup of the model. The prior question—whether or not gasoline/oil prices are endogenous or exogenous—is an important one for the VEC model results we present.

Although our results support the interpretation that the real gasoline and oil price variables are exogenous, we nevertheless present results of two tests with extreme assumptions: that our selected Council of Economic Advisers oil import costs variable is completely exogenous, or that it is completely endogenous. As previously noted, the reference variable we use in tests of the influence of oil import costs is the Council of Economic Advisors oilshrp3 variable, which is a composite variable using (1) West Texas Intermediate crude oil price, (2) net crude oil and oil products imports, and (3) real GDP. Real GDP is unequivocally an endogenous variable in our base model. West Texas Intermediate oil prices are not included; gasoline is the transportation fuel price variable chosen. Oilshrp3 is endogenous in the sense that real gasoline price has a statistically significant effect on it, but no other variables do. According to the arguments presented, real gasoline price, like oilshrp3, is exogenous to short- and long-term non-

energy price variable influence.[20] Net crude oil and product imports are at least partially endogenous, to the extent that the estimate of real consumption of gasoline and other oil products (gas) is significantly influenced by the two financial variables in the model. However, the equation determining gas has the lowest R^2 value.

We examined plots of sequences of reactions of variables leading up to the double dip recessions of 1980–1982 and the Great Recession of 2009. Timing of reaction patterns were inconsistent. Accordingly, our determination of causal ordering was adapted over a few experiments. The primary objective of this and another recent experiment (Santini and Poyer, 2013, 2014) was to test whether the transition from gasoline price to motor vehicle expenditures, then to real GDP, was the proper causal order. Our ordering consistently places real gasoline price, real gasoline spending (surrogate for gasoline consumption), vehicle expenditures, and GDP in that order.

Because we added housing equity, consumer debt, and real gasoline spending, study of the ordering effects for these variables was desirable. When we used graphs to study the patterns of downturns in our model variables following gasoline price shocks, we concluded that the Great Recession housing equity effects were more long term in nature than for other variables; they were deeper and more attenuated. The steady and dramatic continuous decline began earlier (2005) than for other variables during the extended real gasoline price run-up from 2002 to 2008. Although the troughs in motor vehicle spending in the 1973–1981 and 2002–2009 time frames were similar in magnitude, the housing equity decline was much worse in the latter period. Housing equity problems were clearly greater in the Great Recession than in the double-dip recessions.[21]

Final results for the full period suggest that the Great Recession may be an anomaly. Declines in vehicle spending normally precede (or at least accompany) declines in equity and consumer debt.

5.3 LONG-TERM VS. SHORT-TERM CAUSES OF VARIATION IN VARIABLES: OIL PRICE AND QUANTITY

A major question is whether or not short-term oil price volatility is itself damaging to economic growth, in comparison to long-term oil price movements. A feature of the VEC model

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[20] We might say that real gasoline prices are very weakly endogenous in the short run, given that only home equity changes lagged two quarters have a statistically significant effect. It is very important to note, however, that real gasoline prices are strongly endogenous in the very long run (over decades), since four system variables influence real gasoline price in the cointegration equations estimated in this study. This was also true for the Council of Economic Advisors world oil price related wealth effect variable when it was entered into a cointegration equation in one of the three models (see Table A1a of this report).

[21] In the case of the Great Recession, the increase in share of consumer expenditures on gasoline rose steadily, without let-up (Figure 10), while in the case of the increase in share in the double dip recessions, there was a multi-year hiatus in the path of increase (Figure 11). In the latter case, there were two well-spaced motor vehicle technology shocks at the same time as recessions (1973–1975, and 1980–1982). In the former case, there was one motor vehicle technology shock at the time of the single unprecedented (since WWII) recession.

is that it has two components that separately and jointly estimate a prediction of changes of variables. Compared to the widely applied VAR method, the VEC adds estimates of change of variables that are based on current levels of variables. The VEC method uses two stages; the first stage adds an estimate of a cointegration relationship using levels of selected variables. Statistical tests for the existence of cointegration have been developed and are applied—along with the modeler's judgment—to develop the cointegration model predictions.

In the preliminary investigations, we determined that a pair of cointegration equations was statistically indicated. However, it was not obvious which pair to choose. The three variables that were candidates to be paired were (1) log of real gasoline price (lnrpgas), (2) log of real gasoline and oil consumption (lngas), and (3) log of real home equity (lnequity). Although any pairing may provide valuable results, a primary purpose of this analysis is to understand gasoline price and quantity interactions. Accordingly, for this report, the cointegration equations in the models estimated are for lnrpgas and lngas. In one case, the pairing is oilshrp3 and lnrpgas. Because, in the latter case, both variables are highly correlated and both are very closely tied to oil price variation, it is not surprising that they are cointegrated.

The cointegration relationship and tests for the existence of this relationship are based on an assumption that fluctuations of the levels of two variables are inextricably linked to one another in the short and long run. The tested linkage is for co-movement of the two variables, after very-long-term linear trends for each have been accounted for. The very-long-term linear trends can move apart (as they do in the case of lnrpgas and lngas), but when a variable value of one of the two drifts away from the very-long-term trend, it must also be true that the value for the other variable drifts from its trend as well, in a predictable manner related to the drift of the other variable.

Over the time period estimated, the very-long-term movements of real gasoline prices are upward, while the very-long-term movements of real gasoline expenditures are downward. The cause of this pattern is the adoption of a more fuel-efficient transportation system over time. Although most might think of this in terms of adoption of more efficient vehicles, this is not necessarily the only cause of improvement. Better highways and improved traffic control systems could both reduce fuel consumption needs. Optimization of location choices, influenced by gasoline costs, could also be a factor. Difiglio (2014) cites a recent analysis of the Great Recession by Sexton et al. (2012) that attributes loss of housing equity on the outskirts of cities to gasoline prices, as well as losses to vacation and entertainment focused regions. Our analysis examines housing equity (lnequity) over the longer full period from 1951 to 2014, estimating net economy-wide housing equity losses from these three effects. In light of the evidence that people adjust location and home equity value in response to gasoline price increases, adjustment of housing location to reduce gasoline expenditure needs is a possible additional cause of improvement, aside from the more obvious benefits of more efficient vehicles. As earlier discussion indicated, improvements in the efficiency of new vehicles came in pulses (Santini and Poyer, 2013; EPA, 2013), but the cointegration equation for lngas implies that a relatively steady, very-long-term trend in fleet fuel use (mostly used vehicles) existed.

6 BASE MODEL RESULTS

6.1 VERY-LONG-RUN EFFECTS

Table 6 presents base model estimation results for the cointegration equations.

TABLE 6 Base Model Cointegration Equations, Coefficients, z Values, Levels of Significance (very-long-term vector adjustment predictions)

Cointegration Equations	lnrpgas	lngas
lnrpgas	NA	0.0000
lngas	0.0000	NA
lnequity	**-2.44** **(-4.61)[a]**	**0.31** **(2.44)[b]**
lnrcmdebt	0	0
lnRMVE	**4.65** **(5.39)[a]**	**-1.85** **(-9.05)[a]**
lnrGDP	**-3.38** **(-3.47)[a]**	**1.52** **(6.57)[a]**
Constant	25.53	-11.90

[a] Significant at 1% level.

[b] Significant at 5% level.

The base model cointegration model predictions for real price of gasoline and real gasoline consumption are shown in Figure 12. The cointegration equations are as follows:

$$de_{rpgas} = \frac{drpgas}{rpgas} - 2.44\frac{dequity}{equity} + 4.65\frac{dRMVE}{RMVE} - 3.38\frac{drGDP}{rGDP}$$

$$de_{gas} = \frac{dgas}{gas} + 0.31\frac{dequity}{equity} - 1.85\frac{dRMVE}{RMVE} + 1.52\frac{drGDP}{rGDP}$$
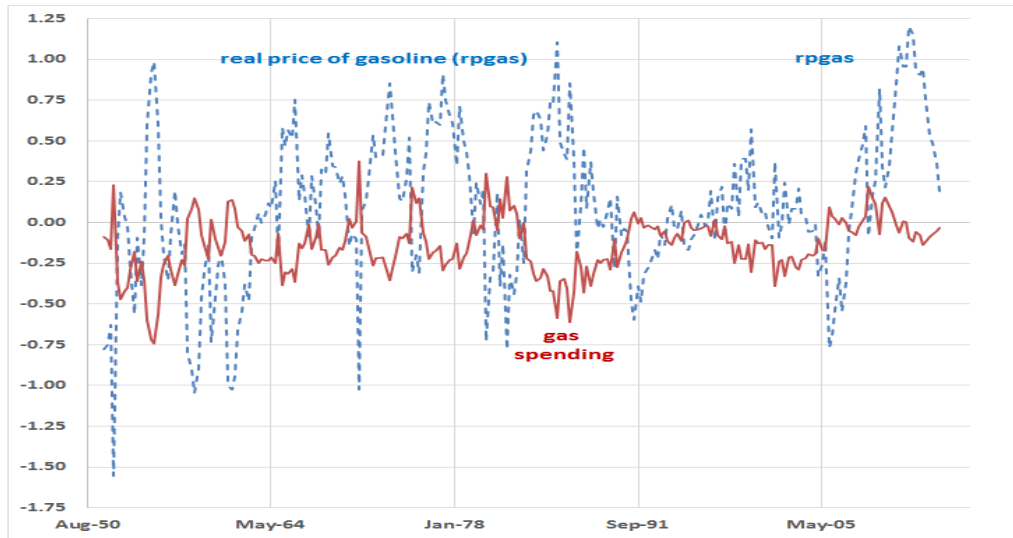
FIGURE 12 Base Model Cointegration Equation Predictions (fractional change per quarter)

Note in the real gasoline consumption equation that the predicted effect of an increase in spending on motor vehicles is a decrease in the consumption of gasoline. This is consistent with very-long-run substitution of capital for energy.

The predicted values for this equation do not reproduce actual values; shocks, or deviations from the very-long-run path, are very large and are quite important in causing recessions. Another observation is that this equation predicts reasonably consistent variability of real gasoline price throughout the estimation period. In fact, the period up to 1972 exhibited very little variation, while the post-OPEC period that followed exhibited very high variation, aside from the 1990s (see Figure 9). During the earlier period, U.S. oil production represented a far larger share of world production than in the more recent period, and the Texas Railroad Commission (Difiglio, 2014) was effective in manipulating prices and U.S. output.[22]

Despite its large inconsistency with actual short-run price movements, the cointegration equation predictions provide insight with regard to important very-long-run trends. Quarter-to-quarter price variation is far larger than real spending variation, which is consistent with a short-run inelastic response of gas spending to price. As price rises, consumption declines. The simple correlation between the contemporaneous gasoline price and quantity predictions is -0.54. However, over the very long run (full period) the average rate of predicted rpgas growth was 0.09% per quarter, and the average rate of predicted gasoline spending (gas) decline was -0.14% per quarter. In the very long run, the average response of consumption of gasoline to average price increases was elastic with respect to price. As discussed earlier, the reductions in gasoline consumption were accomplished in bursts. Technologies that had previously been developed and implemented were relatively suddenly adopted. Thus, the reductions in consumption were likely

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[22] From the fourth quarter of 1951 to the fourth quarter of 1972, real GDP growth was 1.0% per quarter, while from quarter one of 1973 to quarter one of 2013 it was 0.7%.

due to a scientific and engineering culture in the United States that placed a high value on development of more thermodynamically efficient technology. The technology adopted was not immediately developed in response to the real gasoline price increases. It already existed and was much more widely implemented in response to the price increases. This general process of "disruptive" development in niches, followed by eventual mass market success, has been described by Christensen (2003).

Thus, the very-long-run reductions in consumption likely were largely due to a scientific and engineering culture in the United States and other developed nations that placed a high value on improving thermodynamic efficiency, as well as to important rational short-run economic deliberation based on net present value. Sharp sustained price movements induced increased adoption rates for previously existing technologies, which resulted in bursts of substitution of capital for energy (Santini, 1984, 1986, 1992). The adoption process also features regulatory rules (i.e., Corporate Average Fuel Economy regulations) to enforce collective decisions to rapidly adopt known, previously developed technology.[23]

6.2 SHORT- AND LONG-RUN EFFECTS

The VEC equations, coefficients, z values, levels of significance, and R^2 are shown in Table 7. Historically, most research has focused on the effects of oil or gasoline price shocks on the macroeconomy. The results in Table 7 support the findings that short-term shocks have a much stronger effect on real motor vehicle spending than on real GDP as a whole. The addition of the VEC's cointegration model alone does not appear to add much real gasoline price information to these two equations, because the coefficients of the cointegration equation's real gasoline price estimate are essentially zero and thus insignificant.[24]

The added value of this model appears to result from a combination of new variables and the VEC estimation methodology. The addition of the real gasoline consumption variable (lngas) provides a notable amount of new information. In this case, the cointegration equation predictions are estimated to matter a great deal. Statistically significant effects are estimated to be linked to the cointegration equation prediction of lngas for four of the six base model

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[23] This is not to say, however, that the technology is necessarily ready for prime time. Spreading innovations among previously reluctant vehicle manufacturers involves hurried learning and ramping up of new production, which leads to first-generation problems with the technology, which causes purchase delay—waiting for the kinks to be ironed out—by veteran consumers not as urgently pressured by transport cost increases.

[24] Although the individual coefficients for the effect of the two quarters of gasoline price shocks on real vehicle spending are insignificant, the pair are significant (note c, Table 7). The real vehicle spending variable, which includes used and imported vehicles, is not particularly good at predicting sales or production of *domestically* produced *new* vehicles. Kilian (2008) has addressed this thoroughly. We found that the effects of vehicle production changes on real GDP (Santini and Poyer, 2008a, 2008b) were difficult to tease out. It was not until we removed the value of domestic vehicle production from GDP that we obtained a statistically significant estimate of a link from vehicle output to the rest of GDP. The data that allow for such a test only exist from 1967 to the present. The total value of vehicle output for that test included vehicles used for personal consumption and vehicles used for business. This database allows us to examine a longer time series, but with the restriction that we only focus on consumer spending, not transportation equipment investment by businesses.

TABLE 7 Base Model Error Correction Equations, Coefficients, z Values, Levels of Significance, and R^2

			Predicted Variable			
Influence Variable	Δ(lnrpgas)	Δ(lngas)	Δ(lnequity)	Δ(lnrcmdebt)	Δ(lnRMVE)	Δ(lnrGDP)
Long-Term Level Effects						
Coefficients of cointegration prediction of lnrpgas	0.0000 (0.65)	**-0.0078** **(-2.44)[a]**	**0.0077** **(2.34)[b]**	**(-0.0091)** **(-5.38)[b]**	0.0000 (-0.50)	0.000 (-0.36)
Coefficients of cointegration prediction of lngas	0.0000 (1.02)	**-0.0317** **(-2.77)[b]**	0.0000 (-0.91)	**-0.0224** **(-3.66)[b]**	**0.2087** **(6.20)[b]**	**0.0162** **(3.47)[b]**
Short-Term Dislocation (Shock) Effects						
Δ(lnrpgas(-1))	**0.237** **(3.11)[b]**	**-0.057** **(-2.56)[b]**	0.038 (1.32)	-0.005 (-0.42)	-0.113 (-1.36)[c]	0.008 (0.73)
Δ(lnrpgas(-2))	**-0.172** **(-2.26)[a]**	-0.018 (-0.80)	*-0.053* *(-1.83)[d]*	0.008 (0.68)	-0.117 (-1.41)[c]	-0.003 (-0.28)
Δ(lngas(-1))	-0.047 (-0.18)	-0.130 (-1.75)[c]	0.134 (1.40)[c]	0.005 (0.14)	0.068 (0.25)	0.007 (0.18)
Δ(lngas(-2))	0.093 (0.37)	-0.100 (-1.37)[c]	0.071 (0.75)[c]	-0.012 (-0.31)	0.002 (0.10)	0.060 (1.61)
Δ(lnequity(-1))	-0.099 (-0.59)	0.074 (1.49)	**0.488** **(7.62)[b]**	0.031 (1.17)	**0.412** **(2.23)[a]**	**0.061** **(2.41)[a]**
Δ(lnequity(-2))	**0.349** **(2.04)[a]**	**-0.115** **(-2.29)[a]**	**0.223** **(3.45)[b]**	-0.012 (-0.47)	-0.119 (-0.64)	-0.007 (-0.29)
Δ(lnrcmdebt(-1))	0.080 (0.19)	0.190 (1.38)	0.099 (0.60)	**0.249** **(3.42)[b]**	*0.915* *(1.91)[c,d]*	**0.251** **(3.80)[b]**
Δ(lnrcmdebt(-2))	-0.106 (-0.25)	**-0.306** **(-2.19)[a]**	-0.148 (-0.92)	**0.223** **(3.02)[b]**	*0.703* (1.42)[c]	-0.020 (-0.030)
Δ(lnRMVE(-1))	-0.064 (-0.98)	-0.006 (-0.27)	-0.033 (-1.27)	0.004 (0.39)	**-0.245** **(-3.12)[b]**	0.002 (0.18)
Δ(lnRMVE(-2))	0.075 (1.19)	-0.004 (-0.21)	0.006 (0.26)	-0.004 (-0.40)	-0.032 (-0.46)	0.004 (0.44)
Δ(lnrGDP(-1))	0.622 (1.25)	0.140 (0.95)[c]	0.090 (0.48)	**0.156** **(2.01)[a]**	**2.252** **(4.11)[b]**	**0.277** **(3.66)[b]**
Δ(lnrGDP(-2))	-0.538 (-1.07)	0.248 (1.68)[c]	-0.108 (-0.56)	0.106 (1.37)	0.504 (0.92)	0.031 (0.41)
Constant	0.001 (0.17)	-0.000 (-0.10)	0.002 (0.74)	0.002 (1.70)	-0.000 (-0.03)	**0.004** **(4.80)[b]**
R-squared	0.120	0.181	0.507	0.774	0.321	0.566

TABLE 7 (Cont.)

variables. For the error correction equation predicting Δlngas, significant negative effects are estimated for both cointegration equation predictions (lnrpgas and lngas), while a significant negative real gasoline spending shock effect also exists in the first quarter. All six coefficients for the effects that increase transport cost (higher gasoline price, higher gasoline use) are negative, which is consistent with the idea that increasing cost leads to consumption reduction. The estimate that a shock to prior gasoline use and/or a high level of gasoline use leads to reduced current-period use is consistent with the application of engineering and/or management logic to reduce higher-than-desired fuel input requirements. Private and public publications about attributes of vehicles consistently include estimates of fuel efficiency, leaving it to the reader to factor in gasoline price and estimate cost, if they choose to do so. The consistent negative coefficients for the three real gasoline price and three real gasoline spending variables is supportive of the argument that overall transport cost (not just price) should be considered as a driver of macroeconomic fluctuations. Coefficients of lngas are consistently higher than the temporally comparable coefficients of lnrpgas. Thus, the discussion of the probable importance of overall transport cost—emphasizing spending share instead of price or quantity alone—is supported. The separate estimates show that both effects are separately important, and obviously macroeconomic consequences would be worse when both price and consumption rise significantly above very-long-term trends.

This model estimates that there is a significant path from transport fuel use reduction to reduced macroeconomic activity.[25] Because the coefficients for the cointegration equation prediction of lngas are positive and significant for both RMVE and rGDP, in this model lower long-term levels of gasoline consumption are associated with lower levels of economic growth. Recall that long run means 5 years here. Therefore, for the long term (but not very long term), this is interpreted as an indication that reduced fleet vehicle use is associated with reduced macroeconomic activity. Also note that the model implies that there is an inherent tendency for lnrGDP to increase. The constant term for the lnrGDP error correction equation is positive and statistically significant. This is the only error correction equation for which the constant term is estimated to be non-zero.

It has been noted that, for the very long term, there is an inherent tendency for the economy to reduce fleet fuel use, which is reflected in the average full period negative change of

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[25] For the Great Recession, Sexton et al. (2012) argued that a significant number of new homeowners at the outer edges of the metro area were forced into insolvency and had to move back downtown as renters. This would be associated with a significant drop in fuel consumption by those displaced homeowners, and a loss of equity.

lngas in the cointegration equation predictions. These tendencies are consistent with the microeconomic or management logic that reduced fuel inputs for transportation increase long-term growth. It is certainly a premise of macroeconomics that reduced labor inputs (labor productivity increases) enhance economic growth, so this result is, in a sense, trivial and should be expected from a sound econometric model of the macroeconomy.

In the short term, Δln RMVE has essentially no significant influence on any other base model variable. However, in the very long term it is one of the variables that demonstrates a clear cointegration relationship between very-long-term levels of lnrpgas and lngas. Both of the coefficients of ΔlnRMVE in the cointegration equation predictions of lnrpgas and lingas imply that increases in real vehicle spending decrease very-long-term real gasoline spending (lngas) through multiple channels. When lnRMVE increases, lnrpgas is driven upward. In the vector error correction equations, levels of lnrpgas well above trend imply reductions of lngas, so there is a two-step process through from RMVE to rpgas (+) to gas (-). The upward movement of lnrpgas, as Δlnrpgas(-1), also reduces lngas. There is also a one-step direct impact of higher predicted lnRMVE levels in the cointegration equation, because the sign of the coefficient of lnRMVE on the cointegration equation's prediction of lngas value is negative.

Technically, new vehicle spending changes are only able to have an inherently very-long-run effect on the fuel consumption of the fleet of vehicles. In any given year, only about 1/16 of the vehicles are replaced, on average. Thus, it can take several years before the replacement of existing inefficient vehicles with more-fuel-efficient vehicles can have a significant effect on national fleet fuel consumption. This reality is reflected in the base model results, since it is only in the very-long-run that lnRMVE has an effect on real gasoline consumption and price. This reality can be revealed and estimated in the VEC model. In VAR, autoregressive lag, or Granger causality testing, it cannot be confirmed. This can be likened to the concern of economics with understanding and isolating income effects from wealth effects. Vehicle output is a major factor in real GDP, but the fuel use of the new vehicles is a very small fraction of the fuel use of all vehicles (wealth) on the road.

Thus, the nationwide substitution of capital for energy via spending more on new vehicles that use less fuel takes a very long time to accomplish. The cointegration equation coefficients tell us that the response to high fuel costs embedded in the very long run are ultimately positive, expressed through benefits of fuel use reduction on ability to borrow. The long-run system needs for transport cost reduction via reduced fuel use show up clearly and strongly in the coefficients of the cointegration equation predictions of lnrpgas and lngas on Δ (lngas). Coefficients for both variables are negative and easily statistically significant. Accordingly, imposition of high gasoline costs—via either high price (lnrpgas) or high quantity (lngas)—results in a necessary compensating reduction of real gasoline spending (Δ lngas). Applied over multiple years, this short-term effect causes the very-long-run lowering of levels of lngas, and in turn ultimately allow upward changes of debt [Δ (lnrcmdebt)]. Increased short-term debt, in turn, has an immediate short-term output increase effect on lnRMVE and lnRGDP [see coefficients of Δ(lnrcmdebt(-1) on Δ(lnRMVE) and Δ(lnrGDP)]. The effects of Δlnrcmdebt(-1) on ΔlnRMVE are very powerful compared to those on ΔlnRGDP (much larger coefficients). The effects on ΔlnRGDP are more certain, given their estimated statistical significance.

Very-long-term gasoline price reductions also allow more consumer and business (where product transport is important) debt to be assumed [see coefficient of cointegration equation prediction of lnrpgas on Δ (lnrcmdebt)]. However, as noted earlier, and confirmed in Table 7, gasoline prices are exogenous in the short and long term.

The combination of short-, long-, and very-long-run coefficients of VEC model structural elements are very supportive of the Council of Economic Advisors contrast of short- vs. long-run substitution of capital for energy. However, for this process to be well understood, it has been important to define the very long run as a new concept and separate it from the long run. The VEC model structural concept of cointegration essentially forced us to develop this distinction, as did realities concerning the slow effects of more-efficient new vehicles on the fuel use of the capital stock of the entire fleet. Earlier anecdotal/case study comparisons of three multi-year transport cost share (expenditure share) increases during our study period shows that the very-long-run reaction of the economy can take more than the 5 years that we have defined as long run in this paper.

One of the things that we notice about the error correction equations is that the r-squared value of the lnRMVE equation is considerably lower than for the lnequity, lnrcmdebt, and lnrGDP equations. Relative to the latter three equations, the lnRMVE equation has much room for improvement. We theorize that technology shocks related to a sudden transition from negative to positive net present value of fuel savings associated with the substitution of a new generation of transportation technologies represents a key missing lnRMVE equation variable in the base model.

Finally, for the equity variable error correction prediction, the coefficients of the two lngas shocks in the error correction equation are positive, but not individually significant, so expanded gasoline use appears to be associated with short- and long-run home equity increases (see very long run counterexample in footnote 27). The net effect of real gasoline prices is unclear; high predicted lnrpgas levels from the cointegration equation are estimated to be positive, but the net shock effects of lnrpgas after two quarters are negative.

6.3 NET INTERACTIONS OF SHORT-, LONG-, AND VERY-LONG-RUN EFFECTS

In the prior section we considered the implied internal flows of short-, long-, and very-long-run effects by examining coefficients of individual variables and equation types in the base model. We now turn to the aggregate results of the various underlying phenomena, represented by the OIRFs.[26]

The base VEC model OIRFs indicate that a permanent long-run gasoline price increase leads to immediate rapid sharp reductions in transportation related spending by consumers. Both

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[26] The context of the default software presentation in Figure 13 can be questioned. The plots are for the predicted effects of a 1% increase in real gasoline price. It is likely that an actual 1% change would not have the effect illustrated. The estimated effects are due to shocks well above 1% (see Figure 9). Perhaps a more accurate default plot would be for 10% gasoline price increases.

vehicle spending and gasoline spending drop sharply in the short-run—contemporaneously with, and in the first and second quarters following, a gasoline price increase (Figure 13). The gasoline spending results imply that spending on new vehicles is not the only contributor to a recession; the rate of use of existing vehicles also contributes. Home equity and consumer debt also drop sharply initially, but then decline more slowly with smaller proportionate changes. GDP (the rest of the economy) declines are delayed. GDP declines do not start until the first quarter has passed. They decline most steeply in the first year (roughly consistent with Hamilton's [1983] findings of GDP effects three quarters after a quarterly oil price shock), then decline steadily at a lower rate. For the long-run (the 5 years plotted), the predicted effect of a permanent real gasoline price increase is a permanent decline in rGDP, consistent with Tatom's (1981) predicted effects of a permanent energy price increase. Among the five shocked variables, only home equity values are moving upward at the end of the 5-year simulation period.[27]

The consequences of the changes in transportation-related spending feed into future quarter's real GDP levels (Figure 14). Although a 1% increase in vehicle spending has more immediate effect on real GDP than a 1% increase in any other variable, delayed benefits of one percent increases of three other variables (gasoline spending, consumer debt and home equity) are proportionately larger, with largest GDP growth effects arising from a 1% increase in home equity. However, it is important to remember that vehicle spending is more volatile (Figure 13), so total short-term percentage changes in vehicle spending in a recovery from a recession are likely to be considerably higher than these other three variables. Gasoline price increase impacts on real GDP (negative) are plotted in both figures.

Difiglio (2014), citing Sexton et al. (2012), argued that crude oil price shocks not only affect vehicle sales, they also affect equity in built infrastructure (houses, hotels, resorts) in more-remote locations that require long-distance driving. This hypothesis is clearly supported by the OIRF values for home equity in Figure 13, while the relative importance of the hypothesis is supported by GDP effects predicted in Figure 14. Thus, although much of the historical discussion has focused on new vehicle sales, with many analysts contending that the vehicle sales effects were not large enough to be a dominating cause of recessions, the possibility that transport cost increases not only cause direct losses to the transport sector, but also cause indirect losses of wealth in residential and other built assets, creates the possibility that variation in transport costs is a far more important determinant of variation in macroeconomic output than

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[27] lnRMVE drops more sharply than lngas and never rises above lngas over the 5-year period, BUT trends at the end of the period imply that it will do so in the next 5 years. The 5-year results presented are not consistent with the argument that vehicle capital is being substituted for energy. However, the trends are consistent with this happening in the very long run. The steady post-shock lngas downward trend is consistent with implementation of improved new vehicle fuel efficiency slowly working its way into the national fleet. Spending less on both vehicles and fuel implies reduction of transport cost is a major outcome of the gasoline price shock. The discussion here is framed around very-long-term substitution of capital for energy. The short and long run illustrated are inherently about constant technology, since new vehicle efficiency change does not significantly "bite" into fleet fuel use for a few years. It is also possible that the shock induces implementation of production process innovations for motor vehicles that actually also reduce non-fuel cost of ownership of vehicles, thus expanding the national production possibility frontier. The shock may induce much more than just substitution. Aggregate reductions in transport cost can free up discretionary income to allow faster deleveraging and ultimately borrowing and purchase of new housing.
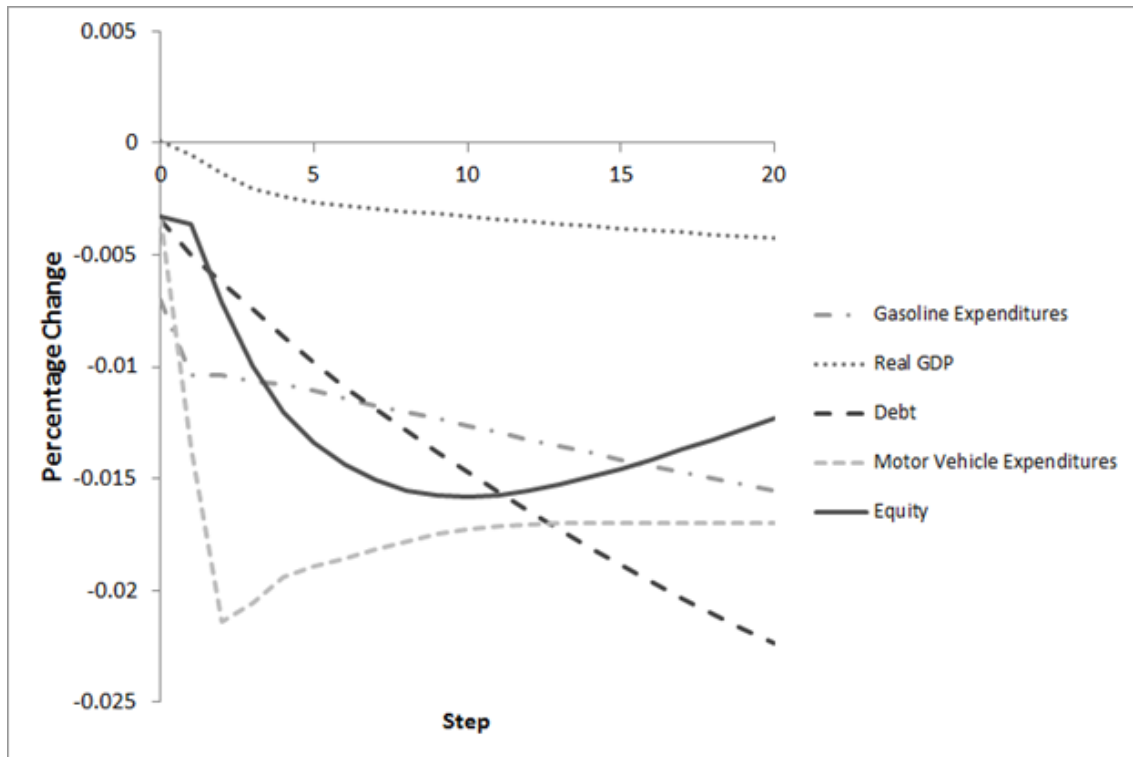
FIGURE 13 Orthogonal Impulse Responses: Effects of a Permanent Gasoline Price Increase on Other Variables
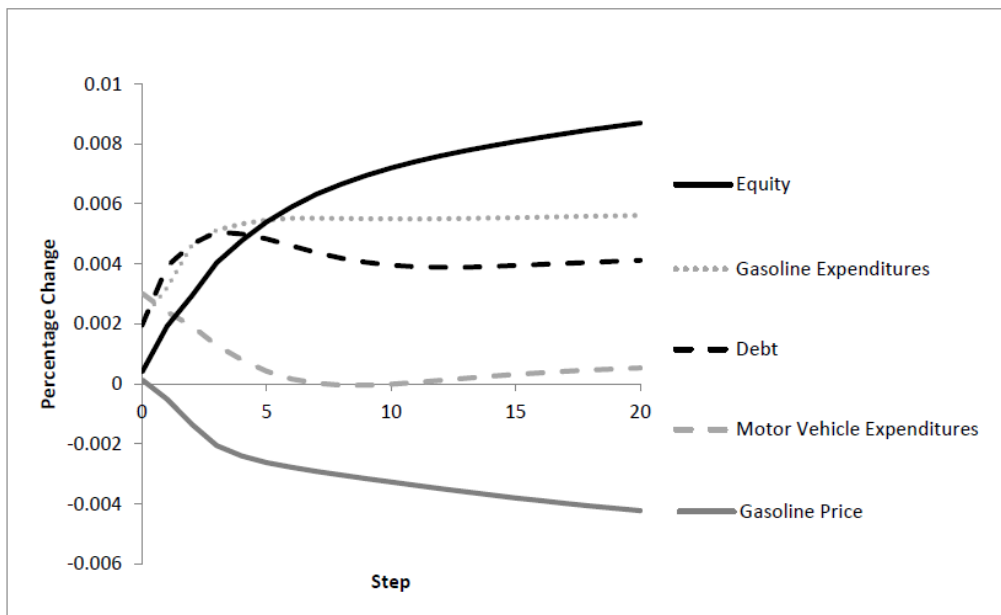

FIGURE 14 Orthogonal Impulse Responses of Other Model Variables (1% change) on Real GDP

has previously been recognized. Accordingly, the importance of prompt short-run mitigation of transport fuel cost increases by means of early injection of reserve supplies may be greater than previously recognized.

One of Santini's attempts to understand the economics of changes in transport technology induced by transport fuel price changes (Santini, 1986, 1992) is based on a two-region transport cost model in which the extent of the market shrinks when transport fuel costs rise.[28] Although the model has no housing sector, theories about land use rent are embedded in the model. Such implied effects of reduced transport cost are easy to summarize and can be argued to be common knowledge:

> "Improved transport allowed land farther off to do the work that land close at hand had done before, whether by producing crops halfway around the world or housing workers out in the suburbs" (Economist, 2015, p. 21).[29]

In Figure 9, we see that transport fuel prices ultimately fell after the double-dip recessions. The years not plotted in Figure 9 (2013 and 2014) have exhibited a fall that is comparable to the fall after the double-dip recessions. Reductions in real gasoline price allowed expanded fuel use and historically made metro edge land (suburbs) affordable, although the process appears to take a very long time to develop. The base model predicts that the greatest benefit of increased fuel consumption enabled by lower gasoline prices and more-efficient vehicles is ultimately an increase in home equity (Figures 13 and 15). However, in the short run, the motor vehicle industry benefits most from availability of fuel. An early boost of sales of more-efficient vehicles following the gasoline price shock ultimately pays off for the economy largely by expanding the affordability of gasoline, which is used to expand the extent of the land market, allowing home equity to increase.

This process unfolds over a longer period than shown in our plots. The three cases of transport spending share increases that promoted adoption of smaller, more-fuel-efficient vehicles were widely spaced (Figure 9). The first peaked in 1958, the second in 1980, and the third in 2008. The fact that the second period lasted 28 years, while the first lasted only 22, is consistent with the larger gains in fuel efficiency that were implemented in the early 1980s. These are very long cycles of economic growth that are only seen in the cointegration equations of the VEC model. The process by which they occur is the same as that used in real business cycle theories.

Major transport cost shocks caused temporary reductions in the construction of single-family houses clearly dedicated to motor vehicle use. The first reduction (1980–1985) was only temporary. The share of houses without garages or carports resumed its steady decline, but only after gasoline prices headed sharply downward and new motor vehicle efficiency had increased to a new plateau for multiple years (EPA, 2013). Consistent with the VEC model estimates of lagged equity effects, the change in the mix of new houses devoted to motor vehicles did not

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[28] They expand when transport costs fall (Stigler, 1951).

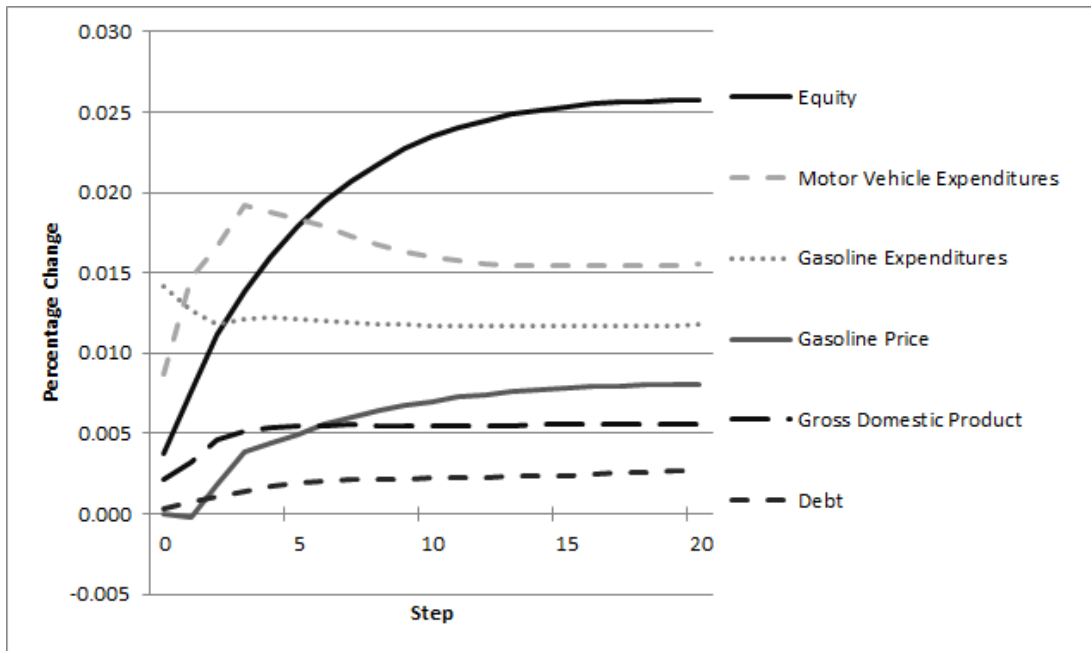[29] The World Bank (2008) summarized this knowledge, with an international emphasis.

FIGURE 15 Orthogonal Impulse Responses to a 1% Increase in Gasoline Expenditures (One manifestation of the transport cost changes for the last part of the sample period is shown in Figure 16.)
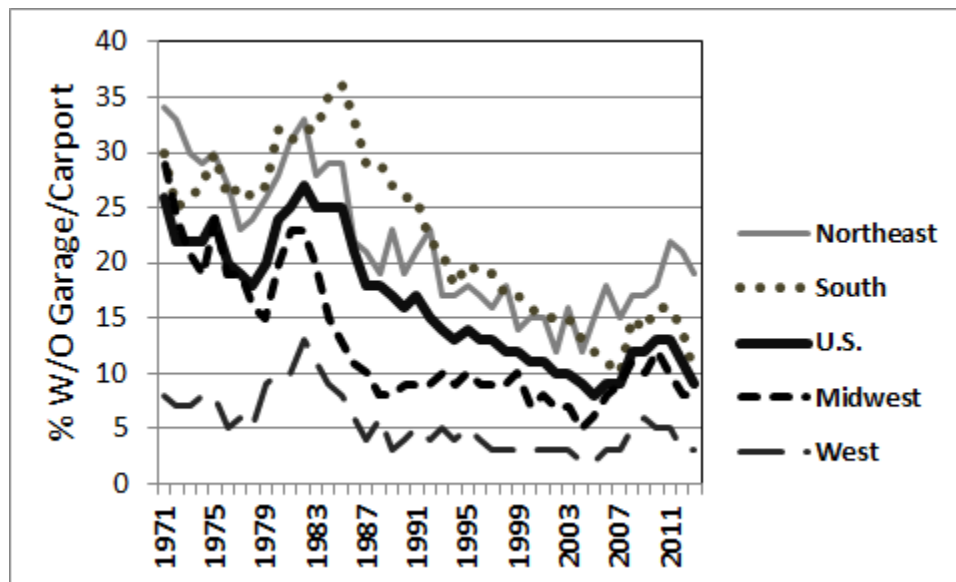

FIGURE 16 Share of New Single-Family Houses without Garage or Carport, 1971–2013

respond quickly. The national share without garages or carports went to 24% in 1980 and remained above that level until 1985. Gasoline prices collapsed from 1985 to 1986, and the share of new houses with garages and carports jumped.

In 1985, the economic historian Blaug wondered why the work of several transport economists had not been incorporated into standard economic thought. These results and interpretations support Blaug's judgment.[30]

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[30] Spatial effects that occurred during the Great Recession are now receiving attention. Sexton et al. (2012) showed that increasing costs of work commutes lowered the value of homes away from the city center. Kneebone and Holmes (2015 documented a shift of jobs away from existing residences, with a greater reduction of jobs within a given commute distance in the suburbs than in city centers. Jobs per commute distance in both locations declined, which could be consistent with regional redistribution of jobs from locations where residences exist to places where they do not (the North Dakota shale oil boom is the prime example). Kneebone and Garr (2009) compared the milder 2001 recession to the Great Recession, noting that the unemployment rate increases in the latter case were similar in suburbs and center cities, where the suburbs had suffered less in 2001, when gasoline price levels and changes were much lower. Morris and Neill (2014) "suggest gasoline prices may be affecting credit risks, property markets, and household wealth in ways the economic literature has so far not fully recognized." They also find that "the relationship of gasoline prices to home values suggests that the broad sensitivity (positive and negative) of home prices to gasoline prices has fallen significantly since 1976." This observation is consistent with the long term decline in gasoline spending by consumers (Figure 9), as a result of improved fuel economy (this was recognized by Morris and Neill [2014]). Morris and Neill also address the effects of differences of rate of change of gasoline prices in conjunction with the ends of two separate housing booms. They reiterate the Glaeser et al. (2012) observation that the end of the later of the two booms (when gasoline price rose) had a far greater retardation of housing price growth in areas further from the central business district than for the former (when the gasoline price dropped).

7 BASE MODEL PLUS A COUNCIL OF ECONOMIC ADVISORS
WEALTH EFFECT VARIABLE

Since the base VEC model was not designed to test for the importance of the wealth effect, a first estimate of the importance of the wealth effect was made by inserting one of the wealth effect variables from the Council of Economic Advisors study. This variable used the expenditure-share-weighting idea in Kilian (2008) and in Edelstein and Kilian (2009) in which the share of personal consumption of gasoline was used to weight the real gasoline price increase. In the Council of Economic Advisors case, the share of value of oil imports in real GDP was used as a weighting factor for oil price increases. The variable used in this revised model was the oilshrp3 variable provided by the Council of Economic Advisors.

If the oilshrp3 variable was indeed a dominant cause of recessions, then inclusion of it in our base model should have sharply diminished the estimated importance of most variables. This did not happen. In fact, the short-run results for estimated GDP damages from a real gasoline price increase were essentially unchanged. The negative long-run GDP impulse estimates did become less severe. However, as far as short-run recession mitigation is concerned, the implication is that reduction of real gasoline price impacts remains as important for recession prevention as originally estimated (Figure 17). Further, this plot only addresses effects of real gasoline prices. The models with oilshrp3 inserted have two competing variables that (1) infer key input costs (oil) determining gasoline price (i.e., oilshrp3), or (2) actually measure gasoline price (rpgas).

The VEC imposes a number of estimation issues on the analyst using the software. The ordering of entry of variables can be important. If a variable is placed first in the order, it is said to be exogenous (see Table A-1 in the appendix for estimation results with oilsrhp3 treated as exogenous). If it is placed last in the order it is endogenous (see Table A-2 in the appendix for estimation results with oilsrhp3 treated as endogenous). If placed at intermediate entry points it is neither exogenous nor endogenous. As discussed earlier VEC estimation results depend on the sequence of entry of variables. VEC rules require that cointegrated variables must be entered first. Thus, since we estimated a model where oilshrp3 was entered first and rpgas second, this automatically tested whether or not these two variables were cointegrated. Because both variables are tied to oil price, it is (in retrospect) unsurprising that they were estimated to be cointegrated. Signs of coefficients were identical and measures of statistical significance were also nearly equal (see Table A-1 in the appendix). Post-estimation examination of oilshrp3 showed that oil price variation dominated its short-run variation.

An interesting anomaly was the first and second quarter impulse response function of the wealth effect price change variable on GDP. In the initial (contemporaneous) and first quarter, it was estimated that the impulse response of the wealth effect variable was positive (Figure 18). Thus, considering these OIRFs alone, the implications for recession management were that elimination of the wealth effect for the United States could worsen U.S. recessions caused by world oil price increases.
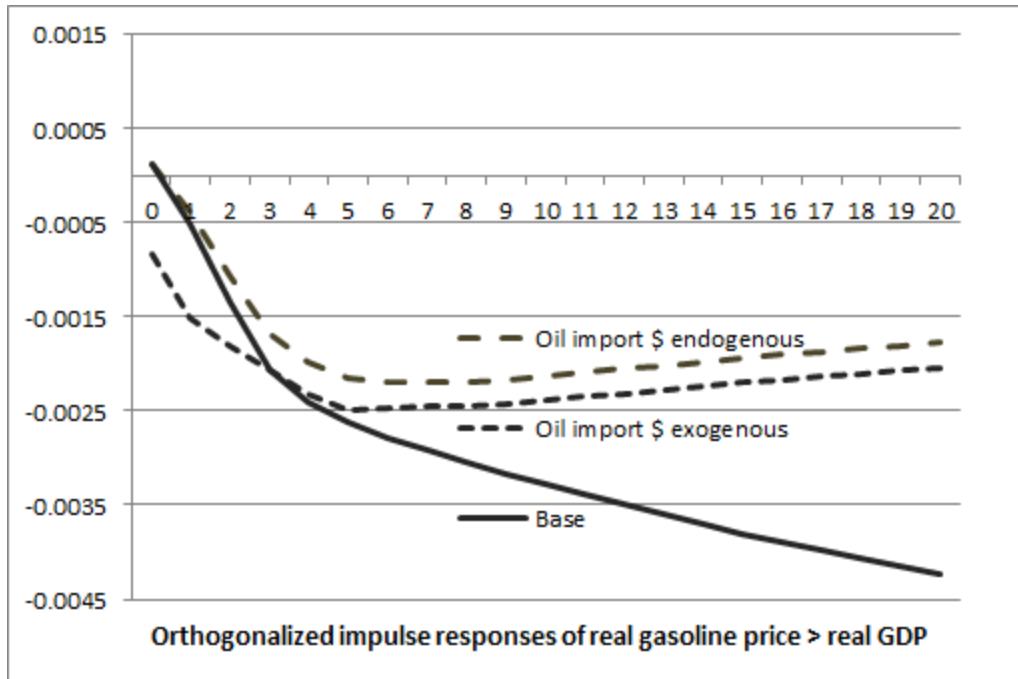
FIGURE 17 Predicted OIRF of Gasoline Price on Real GDP: Base Model vs. Two Wealth Effects Tests
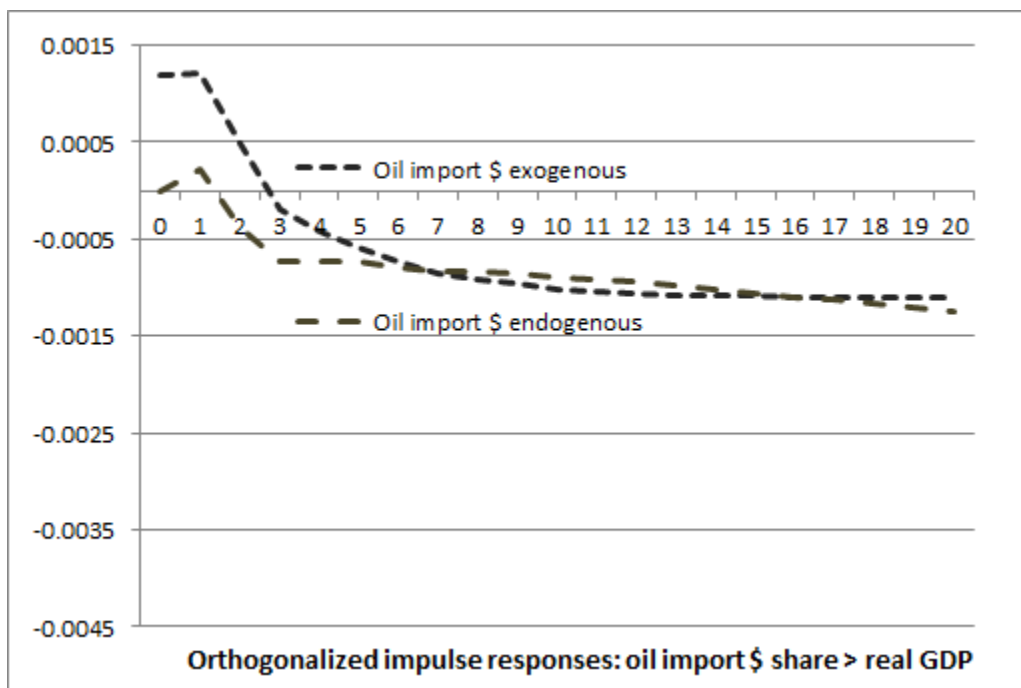
FIGURE 18 Wealth Effect Variable OIRF on Real GDP: Exogenous vs. Endogenous Estimates

In Figures 19–24, we present the OIRFs for rpgas with and without the oilshrp3 model added, for the exogenous case. The OIRFs for oilshrp3 are also presented, and the sum of OIRFs for both oilshrp3 and rpgas are presented. Because a 1% world oil price shock would theoretically cause less than a 1% change in gasoline price, this summation overstates the impacts of a world oil price shock. Further, because the import share should decline after such a shock, the oilshrp3 effects would subside more than in the case of a world oil price shock alone. Consider the sum to be an upper bound estimate of impulse response to a permanent world oil price increase.

A world oil price shock, where world oil is priced in dollars, would push both oilshrp3 and real gasoline prices up simultaneously. Inclusion of the oilshrp3 wealth effect variable in the VEC model reduced the predicted effect of rpgas alone, but when jointly considering both rpgas and oilshrp3, the overall transport fuel cost effects appear to have roughly the same total effect through about 2.5 years. In Figure 19, compare the rpgas curve in the base model to the "exogenous sum" curve.

Although the effects of oilshrp3 on the prediction for rpgas on rGDP are not proportionately large, the underlying rpgas impulse responses do often vary across the five variables presumed to cause rGDP. The estimated effect of rpgas never increases when oilshrp3 is added. Consistent with this, although with a lag, the results do show the negative effect of the rpgas impulse decreasing.

Figure 20 shows the effects of rpgas on gas consumption with and without oilshrp3 entered exogenously in the model. These results imply that consumer gas consumption is driven by gasoline price in the same manner in both versions of the model. Concerns over oil imports do appear to have an added secondary effect in reducing gasoline consumption. Perhaps consumers

FIGURE 19 Comparison of OIRFs for rpgas on rGDP with and without oilshrp3 Added
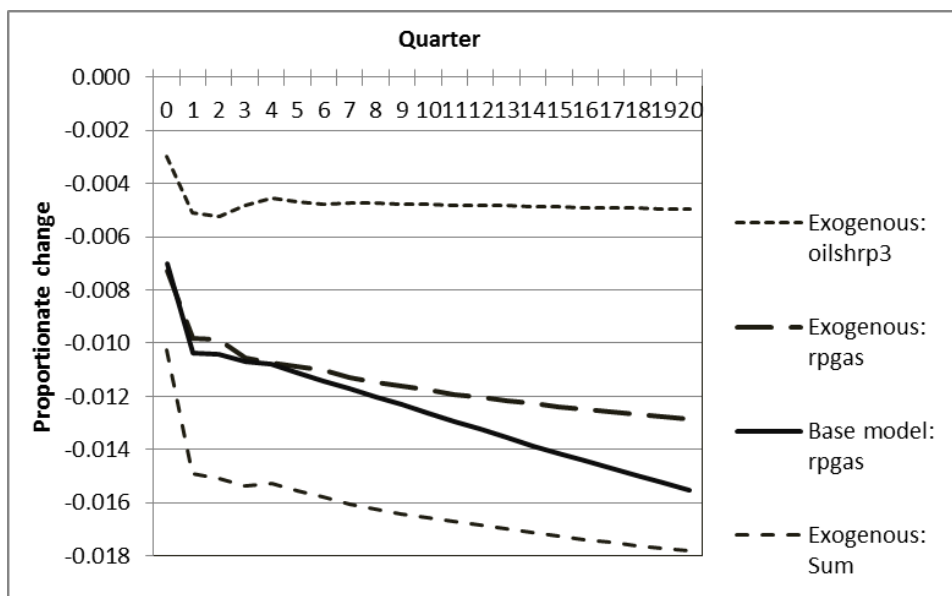
FIGURE 20 Comparison of OIRFs for rpgas on Gas Consumption with and without oilshrp3 Added

have an even greater tendency to conserve fuel in the event of wars in the Middle East, when concern over adequate long-term gasoline availability may peak. Given the transport cost effects arguments presented earlier, the greater reduction in gasoline consumption when oilshrp3 is considered is consistent with the earlier prediction of a gentle recovery (Figure 17).

The OIRF of rpgas on rcmdebt is slightly reduced in absolute magnitude. The OIRF of oilshrp3 on rcmdebt is fairly small relative to the rpgas OIRF (Figure 21).

The oilshrp3-induced change of the OIRF of rpgas on RMVE overall is significant, reducing the first-year impulse magnitude by about half, and then reducing the long-run impulse magnitude almost to zero after 5 years (Figure 22). However, in the initial (zero) quarter, the vehicle spending reduction caused by rpgas actually increases slightly. The overall effect of adding oilshrp3 is to reduce the degree of negative response in the long run. Perhaps the response of the nation to transport fuel cost shocks occurring in conjunction with a rising oil import share is more serious than when oil import share is relatively unchanged. Possibly long-term concerns over fuel supplies and costs are greater when oil supply from other nations is restricted, causing greater adoption of fuel efficiency and thereafter greater sales of more efficient vehicles.

In the case of equity, the effects of oilshrp3 are very large (Figure 23). The OIRF of rpgas on equity drops sharply when oilshrp3 is added to the model; the effect of oilshrp3 is even larger than the base case estimate for rpgas. Perhaps wars in the Middle East create unusual levels of concern over investing over the very long term in locations where commuting costs are high. Most likely a good portion of the flow of funds outside of the United States is taken out of the pool of funds used to support residential investment. It seems reasonable to presume that newly enriched oil-exporting nations would use much of the funds extracted from the United States for purchases other than financial products supported by U.S. mortgages.
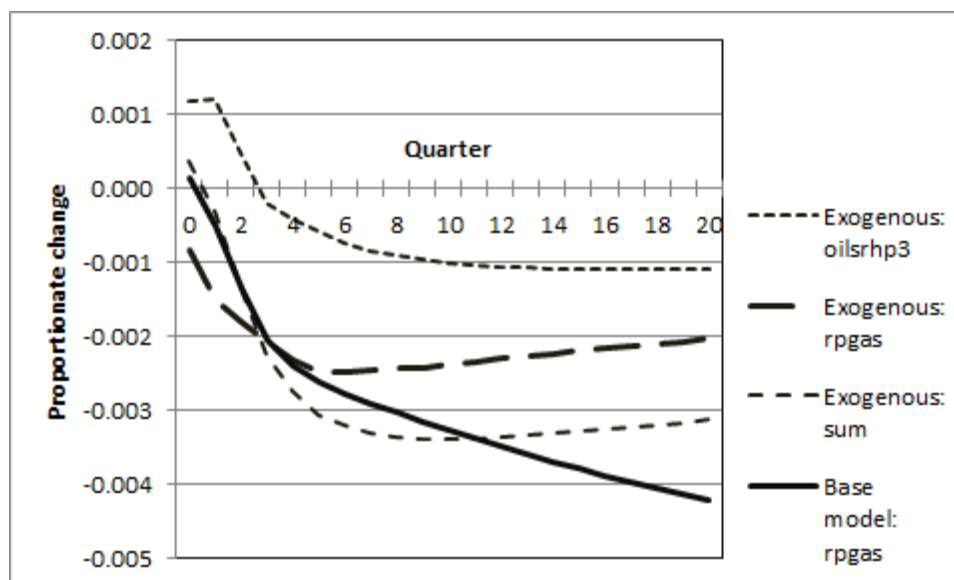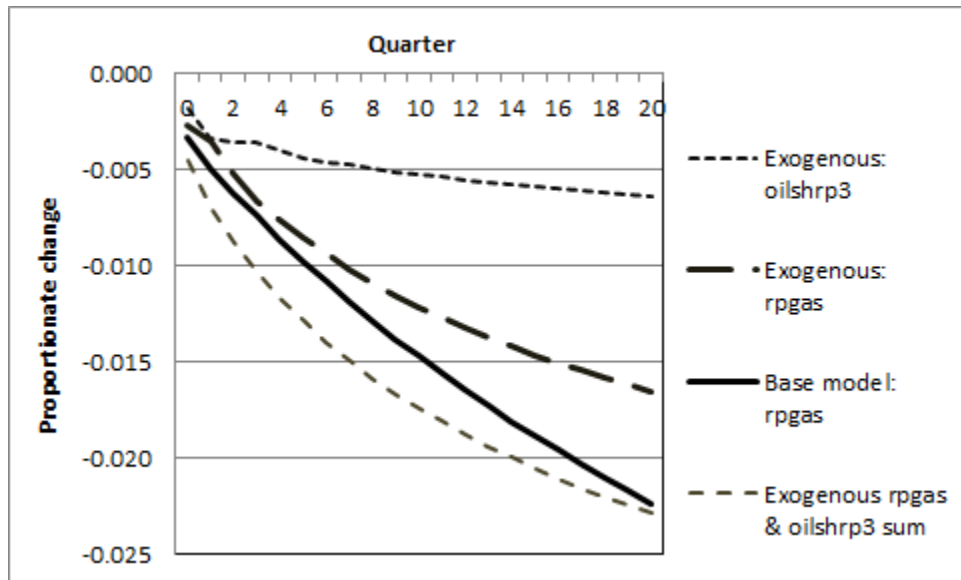
FIGURE 21 Comparison of OIRFs for rpgas on rcmdebt with and without oilshrp3 Added
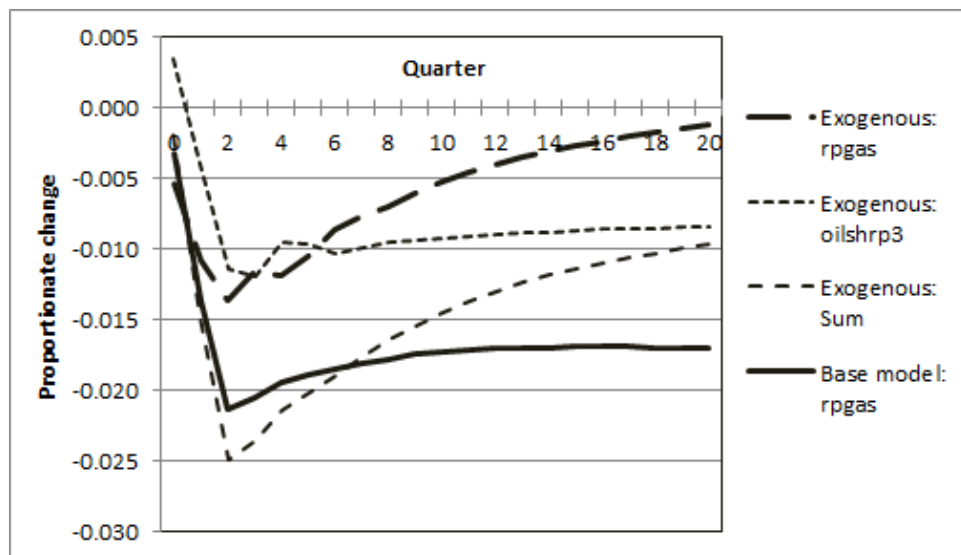
FIGURE 22 Comparison of OIRFs for rpgas on RMVE with and without oilshrp3 Added
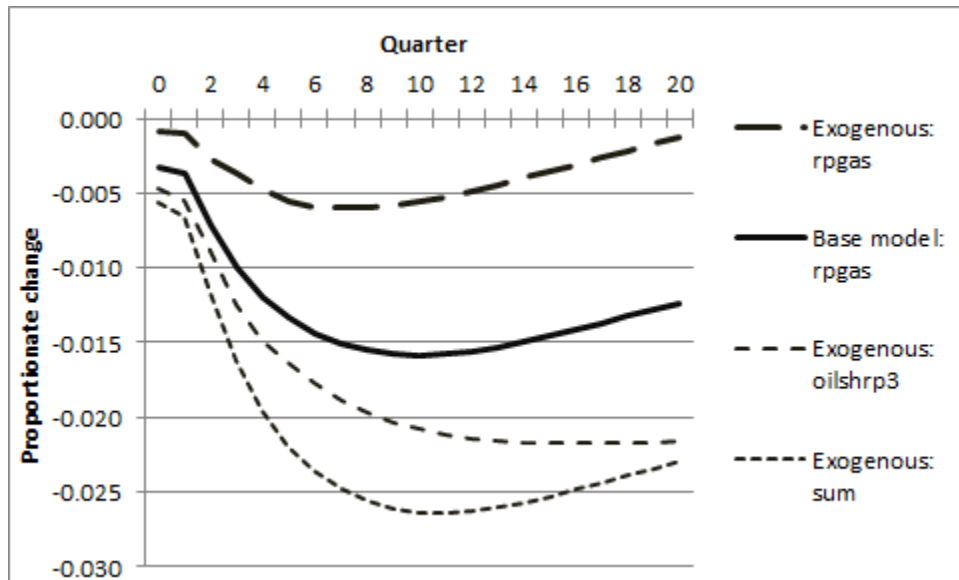
FIGURE 23 Comparison of OIRFs for rpgas on Equity with and without oilshrp3 Added

Finally, Figure 24 plots the OIRFs of the two energy price variables on themselves and on each other. The estimated OIRF of rpgas on itself does not drop significantly after inclusion of oilshrp3. An interesting result is that oilshrp3 has little effect on itself, while rpgas increases tend to cause further increases. This would imply that an attempt to reduce oilshrp3 increases by supplying more West Texas Intermediate crude oil would not have as lasting benefits as attempts to reduce rpgas increases by supplying more gasoline.
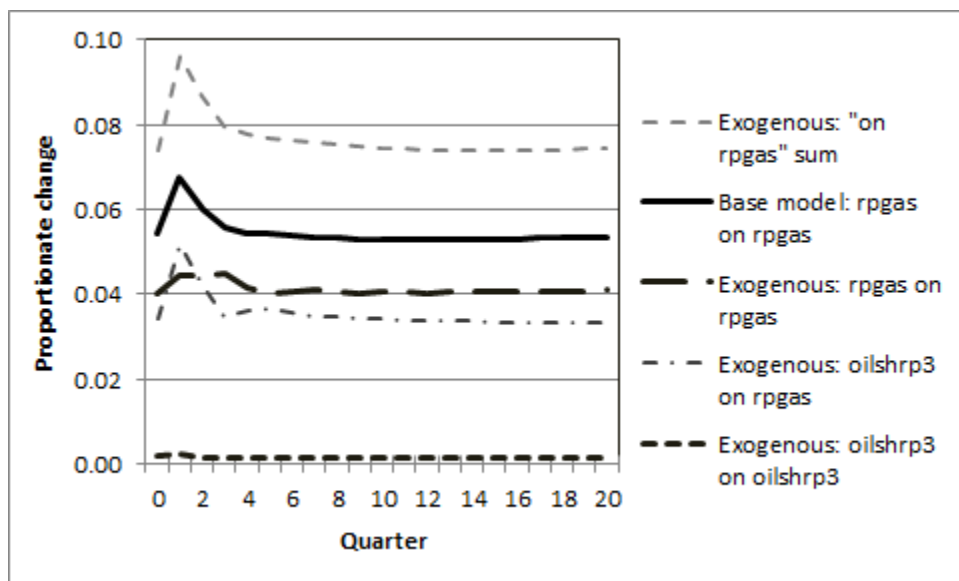
FIGURE 24 Comparison of OIRFs for rpgas on and oilshrp3 on Themselves and Each Other

8 CONCLUSIONS AND INTERPRETATIONS

Transportation fuel cost shocks (resulting from real gasoline price and real gasoline spending) are inferred to be far more important determinants of macroeconomic activity than previously recognized. When both real gasoline price and real gasoline spending combine in the very long run (more than 5 years) to create a large net increase in share of consumer spending on gasoline, unusually severe and/or frequent recessions are likely to follow the multi-year run-up. Not all recessions are the same (Santini, 1985b, 1985c). Transitory energy price shocks[31] are unlikely to induce significant pulses of technological change in new motor vehicles.

Significant long-run transportation fuel cost increases "permanently" (more than 5 years) retard economic growth, consistent with Tatom's (1981) prediction. However, these fuel cost increases are reversed in the very long run, because pulses of capital-for-energy substitution ultimately push consumption of transportation fuel, and thereby prices, down. This phenomenon fits the real business cycle theory that Mankiw (1990) said might gain traction in coming decades as an explanation for fluctuations in macroeconomic activity.

Short-, long-, and very-long-run responses to gasoline price increases differ significantly. In the long run, significant intra-sectoral restructuring of transportation technology occurs as old production capacity is shuttered and new facilities are built. These transitions are associated with unusually severe recessions or closely spaced recession pairs. In the very long run, inter-sectoral shifts away from transportation fuel use and toward other goods and services were accomplished via product and process innovation in transportation services. Very long periods of sustained economic growth followed.

Light-duty motor vehicles provide both business (commuting) and consumption services to the economy. Kilian (2008) has shown that declines in vehicle spending following a gasoline price increase are not confined to light-duty vehicles. On the consumption side, sales of recreational vehicles, pleasure boats, and pleasure aircraft all decline. On the business investment side, heavy truck sales also drop. Impacts on the economy resulting from gasoline price shocks are pervasive, affecting vehicle sales and use, home ownership, credit markets, and leisure activities.

Real transportation fuel price and real expenditure are cointegrated in the very long run. The estimated cointegration equation implies that real transportation fuel expenditures are elastic over decades with respect to transportation fuel price. The hypothesis is that a U.S. scientific-engineering-management culture and system (patents, long-term research and development, intellectual property rights) that values sustained efforts to improve thermodynamic efficiency enables intermittent bursts of technology transition (capital for energy substitution combined with process innovation to reduce vehicle costs) in response to very-long-run (more than 5 years) transportation fuel spending share increases.

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[31] Tatom defined transitory increases as shocks, contrasting them with permanent price increases, which are simulated in the VEC model graphs we have presented.

Although financial problems created by overleveraging are undoubtedly what made the latest recession the Great Recession, the cumulative long-run changes in gasoline spending share that contributed to the recession were as bad as those that preceded the double-dip recessions of 1980–1982, which together were also a very severe macroeconomic contraction. When estimated for the full post-WWII study period, the typical impulse response function ordering of changes of chosen variables indicates that declines in transportation spending (vehicles and fuel) in response to transportation fuel price increases are the usual leading cause of recessions, given their very sharp short run contractions. However, both equity and consumer debt also decline immediately and significantly, and later achieve similarly proportionate changes relative to real gasoline spending and real motor vehicle spending after about 2.5 years. The Great Recession was exceptional with respect to the unrelenting, continuous, large incremental increase in the share of consumer spending devoted to gasoline. In this unusual case, sharp equity declines began well before vehicle spending declines.

Greene, Lee and Hopson (GLH, 2012) identified three effects of oil prices that must be considered when estimating macroeconomic damage: (1) dislocation losses due to oil price shocks, (2) loss of GDP due to the higher monopoly price of oil, and (3) transfer of wealth in the form of monopoly rents to oil exporters. The statistical modeling in this report supports the existence of all three effects. The wealth effect, emphasized in a recent 2014 report by the Council of Economic Advisors is only one of the three. Consistent with estimates of GLH, dislocation (price shock) and price-level effects remain very important, even if the wealth effect is eliminated. Estimates of the base VEC model compared to modified models to test the importance of the wealth effect variable chosen by the Council of Economic Advisors indicate no short-run GDP benefit of elimination of the wealth effect by eliminating net imports. In the short run, the VEC estimates imply that shock and price-level effects (not wealth effects) dominate the damages from price increases induced when short-term transport fuel demand exceeds supply, or supply contracts relative to demand.

The recent Council of Economic Advisers (2014) report asserted that selected composite "wealth effect" oil price shock variables have alone been a dominant cause of macroeconomic fluctuations. They used a distributed lag econometric estimate of single wealth effect variables on real GDP or employment. This report constructed a very different comprehensive transport-cost-related dynamic description of the macroeconomy using six variables in a VEC model. This experiment produced a set of impulse responses that were relatively robust to competition from the best Council of Economic Advisers wealth effect variable, oilshrp3. Consistent with the underlying theory that variation in transport cost dominates macroeconomic fluctuations, real gasoline prices (levels and changes) were estimated to have a much stronger total effect than this oil price shock (change) variable weighted by net import costs.

Contrasting the U.S.-based results shown here with world-based results by Oladosu (2015), oil and refined products prices appear to be endogenous to net oil importing nations collectively (consistent with Kilian and Murphy, 2014); however, in the short run they are probably are exogenous to any single nation. Thus, given the implications that transport cost increases create a wider range of short-run economic damages than previously estimated, world transportation fuel reserves to mitigate world supply shortfalls and subsequent recessions appear to be more important for global economic stability than previously thought.

This model does not include financial variables that have traditionally been chosen by those convinced that only money matters. However, the results clearly suggest that money, in the form of consumer debt and housing equity, are key parts of a gasoline cost induced bust-to-boom cycle. Statistically significant relationships estimated in the cointegration equation portion of the vector error correction methodology used here appear to be critical to this new prediction of strong interrelationships of transport cost, consumer debt, housing equity and real GDP. The exact mechanisms, and the extent to which debt management strategies might overcome an absence of physical supply of oil or gasoline, are worthy of careful study. The results imply that the case that energy cost matters as well as monetary policy—transportation energy in particular—is strong.

Kilian (2008) said that, "little would be lost by focusing on gasoline prices alone in studying the response of consumer expenditures." In fact, it may be that much has been lost by the failure to focus on transport fuel prices and costs.

Table 3 compared several theories and statistical tests. The results presented here suggest that there is an element of truth in each theory and that none can be ignored. The aggregate behavior of the macroeconomy is quite complex. The development and availability of the VEC model, which is itself considerably more complex than previously employed statistical concepts, appears to be helpful in sorting through the many complex interactions that matter.

9 NEXT STEPS

In the simpler model that we documented in 2013, the measure of national macroeconomic activity was total employment. In that case, our estimates provided evidence of a structural break in the 1980s. We speculated that this structural break resulted from the delayed fleet-wide fuel consumption reduction benefits of a pulse in new vehicle fuel economy early in the decade. Our cointegration equation estimates (Figure 12) imply a quiescent period for gasoline price and spending volatility in the 1990s (which actually occurred; see Figure 9) following this structural break. Did adoption of fuel-efficient technology push world oil prices down and reduce volatility of prices? Was it really the low level of transport fuel cost and relative stability of prices that led to the steady 1990s growth that gave economists the impression (since dashed) that monetary policy was finally working well? Why were gasoline prices so stable up until 1972, in contrast to the predictions of the gas price cointegration equation estimated over the full sample period? Further investigation may reveal important structural breaks in this more-complex model of transport cost and macroeconomic activity. Hamilton's original 1983 contribution implied a structural break after OPEC.

Since these results imply that macromodels may be miss-specified, are policy conclusions drawn from today's macromodels reliable? Perhaps the inner workings of macromodels shocked by permanent transportation fuel cost shifts should be contrasted with the patterns of variable changes shown here.

More likely, it is too early to conduct such experiments. Potentially important omissions of analysis have been discussed in the paper.

There is no representation of the reaction transportation equipment investment has to transportation fuel cost changes. This is a more difficult area to analyze, because no quarterly records of price and consumption of fuel used by businesses are readily available in the National Income and Product Accounts. Diesel fuel, rather than gasoline, is the dominant fuel used by businesses. However, to the extent that oil prices have been repeatedly tested for an aggregate effect on macroeconomic activity, there is no reason to neglect testing the effects oil prices have on transportation equipment investment, and those transportation equipment investment have on macroeconomic indicators such as real GDP and total employment. Using gasoline price, Kilian (2008) found that sharp reductions in heavy truck sales did follow gasoline price shocks. No analysis of outputs of new aircraft, agricultural equipment, rail equipment, or ships and barges are included in cited references. However, Kilian and Murphy (2014) addressed the business side when they used a world shipping index in their tests for endogeneity of world oil prices.

Descriptive arguments suggest that the share of gasoline expenditures within personal consumption expenditures is likely to be a more valuable single predictor of macroeconomic activity than gasoline price or gasoline consumption alone. These arguments should be tested econometrically in spin-off models derived from this base model.

Should the share of gasoline expenditures within personal consumption prove to singly be nearly as adequate as both gasoline spending and consumption entered separately, it would be possible to reduce the key variable count by one. This would allow insertion of at least one additional variable. To satisfy those who doubt the importance of transport costs, it will probably be necessary to test the effects of other financial variables as competitors to transport cost for explanation of macroeconomic activity. Most likely, there will also be a demand for testing of longer lags for variables designed to test for effect of monetary policy, which would create pressure to delete some variables in this model to allow adequate degrees of freedom for acceptable statistical tests.

However, the issue here is what causes the onset of a recession and what can best mitigate it. It is well known that the influence of monetary variables under the influence of the Federal Reserve involves a long time lag. That money matters is not an issue, given the results of this model and prior research that included both money and energy variables (Santini, 1986, 1987, 1992, 1994). Thus, a key question for statistical extensions of this work would be the degree to which (1) two quarters of money variable adjustment would compete with (2) two quarters of gasoline supply increase for purposes of mitigating recessions.

The "wealth effect" variables of the Council of Economic Advisors (2014) and of Greene, Lee and Hopson (GLH, 2012) are different in structure. The Council of Economic Advisors variable is a composite that includes oil price change and net imports. Because the VEC model accounts for both price change and level effects, it seems desirable to separately test for the effect of oil prices and net imports, allowing effects of each to be identified within the dynamic system. Further, since the work of GLH places emphasis on OPEC it might be informative to conduct separate tests for the effect of OPEC imports and other net imports.

Ultimately, despite far more data and much more sophisticated econometric methods than those available in the 1980s, the tests that are now possible remain limited. Not only are there restrictions on the number of variables that can be included when good variables exist, there are also restrictions on the availability of good variables, due to prior prejudices that energy did not matter to macroeconomic activity. Bloesch and Gourio (2015) provide one example, in which considerable data exists on weather patterns, but not in a form that can be trusted for econometric testing of macroeconomic impacts. We mentioned the lack of price data for diesel fuel as a constraint in accurately estimating how transportation equipment investment responds to the prices of fuels used in that equipment.

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APPENDIX: TWO MODELS ESTIMATED WITH OILSHRP3 ADDED FIRST AND LAST

TABLE A-1a Oilshrp3 Exogenous Model Cointegration Equation Coefficients, z Values, Significance (very-long-term vector adjustment predictions) (associated with Table A-1b)

Cointegration Equations	oilshrp3	lnrpgas
oilsrhp3	1	0.0000
lnrpgas	0.0000	1
lngas	-0.739 (-1.42)	-16.958 (-1.24)
lnequity	**-1.028** **(-3.80)[a]**	**-27.29** **(-3.85)[a]**
lnrcmdebt	**0.854** **(2.28)[b]**	**22.17** **(2.26)[b]**
lnRMVE	**3.072** **(5.36)[a]**	**79.44** **(5.28)[a]**
lnrGDP	**-3.623** **(-4.49)[a]**	**-94.20** **(-4.45)[a]**
Constant	-22.067	**-568.9**

[a]   Significant at 1% level.

[b]   Significant at 5% level.

TABLE A-1b Oilshrp3 Exogenous Model Error Correction Equation Coefficients, z Values, Significance, and R²

				Predicted Variable			
Variable	oilshrp3	Δ(lnrpgas)	Δ(lngas)	Δ(lnequity)	Δ(lnrcmdebt)	Δ(lnRMVE)	Δ(lnrGDP)
Long-Term Levels Effects							
Coeff. - cointegration prediction of oilshrp3	-0.011 (0.72)	0.614 (0.70)	0.240 (0.89)	*-0.635 (-1.86)* [a]	**0.511 (3.68)**[a]	**-3.602 (-3.70)**[a]	**-0.404 (-2.96)**[a]
Coeff. - cointegration Prediction of lnrpgas	0.000 (0.71)	-0.023 (-0.70)	-0.009 (-0.87)	*0.025 (1.88)*[a]	**-0.0198 (-3.72)**[a]	**0.134 (3.60)**[a]	**0.015 (2.92)**[a]
Short-Term Dislocation (shock)							
Δ(oilshrp3(-1))	0.033 (0.38)	**6.980 (2.82)**[a]	-0.021 (-0.03)	1.003 (1.04)	**-1.186 (-3.04)**[a]	1.876 (0.69)	0.536 (1.40)
Δ(oilshrp3(-2))	**-0.502 (-5.58)**[a]	**-6.607 (-2.59)**[a]	0.187 (0.24)	-0.139 (-0.14)	0.160 (0.40)	-0.780 (-0.28)	-0.084 (-0.21)
Δ(lnrpgas(-1))	*0.006 (1.77)*[c]	0.106 (1.07)	*-0.057 (-1.91)*[c]	0.025 (0.64)	0.021 (1.38)	-0.137 (-1.26)	-0.003 (-0.20)
Δ(lnrpgas(-2))	**0.009 (2.80)**[a]	-0.022 (-0.24)	-0.021 (-0.73)	-0.044 (-1.20)	0.003 (0.17)	-0.079 (-0.76)	0.002 (0.11)
Δ(lngas(-1))	0.009 (1.00)	-0.057 (-0.22)	*-0.131 (-1.69)*[c]	0.087 (0.88)	0.045 (1.11)	0.036 (0.13)	-0.010 (-0.25)
Δ(lngas(-2))	0.003 (0.33)	0.114 (0.46)	-0.103 (-1.36)	0.038 (0.40)	0.018 (0.45)	0.088 (0.32)	0.058 (1.49)
Δ(lnequity(-1))	0.001 (0.12)	0.033 (0.20)	0.074 (1.45)	**0.489 (7.49)**[a]	0.023 (0.86)	*0.310 (1.67)*[c]	**0.056 (2.13)**[b]
Δ(lnequity(-2))	0.005 (0.78)	0.232 (1.38)	*-0.100 (-1.95)*[c]	**0.210 (3.20)**[a]	0.003 (0.12)	-0.221 (-1.18)	-0.016 (-0.60)
Δ(lnrcmdebt(-1))	0.008 (0.45)	-0.145 (-0.30)	*0.290 (1.94)*[c]	0.241 (1.26)	**0.253 (3.28)**[a]	**1.298 (2.40)**[b]	**0.310 (4.07)**[a]
Δ(lnrcmdebt(-2))	0.008 (0.46)	-0.287 (-0.58)	-0.227 (-1.50)	-0.002 (-0.01)	**0.223 (2.85)**[a]	**1.126 (2.06)**[b]	0.037 (0.47)
Δ(lnRMVE(-1))	-0.001 (-0.49)	-0.085 (-1.24)	-0.007 (-0.37)	-0.014 (-0.55)	0.003 (0.30)	**-0.265 (-3.52)**[a]	-0.003 (-0.29)
Δ(lnRMVE(-2))	0.002 (1.03)	0.072 (1.17)	-0.006 (-0.34)	0.013 (0.53)	-0.004 (-0.45)	-0.063 (-0.92)	-0.000 (-0.05)
Δ (lnrGDP(-1))	0.016 (0.94)	0.569 (1.14)	0.098 (0.64)	0.000 (0.00)	**0.182 (2.32)**[b]	**2.308 (4.19)**[a]	**0.264 (3.41)**[a]
Δ(lnrGDP(-2))	-0.020 (-1.14)	-0.287 (-0.58)	0.189 (1.24)	-0.106 (-0.55)	0.087 (1.11)	0.622 (1.13)	0.024 (0.31)

			Predicted Variable				
Influence Variable	oilshrp3	Δ(lnrpgas)	Δ(lngas)	Δ(lnequity)	Δ(lnrcmdebt)	Δ(lnRMVE)	Δ(lnrGDP)

Short-Term Dislocation (shock) (cont.)

Constant	-0.0003	0.001	-0.000	0.001	**0.002**	-0.000	**0.004**
	(-1.27)	(0.19)	(-0.14)	(0.54)	**(2.18)[b]**	(-0.03)	**(4.34)[a]**
R-squared	0.180	0.186	0.170	0.503	0.779	0.351	0.570

[a]   Significant at 1% level.

[b]   Significant at 5% level.

[c]   Significant at 10% level.

**TABLE A-2a Oilshrp3 Endogenous Model
Cointegration Equation Coefficients, z Values, and
Significance (very-long-term vector adjustment
predictions) (associated with Table A-2b)**

Cointegration Equations	lnrpgas	lngas
lnrpgas	1	0
		(omitted)
lngas	0	1
	(omitted)	
lnequity	**-3.42**	**1.11**
	(-4.38)[a]	**(3.82)[a]**
lnrcmdebt	0	0
	(omitted)	(omitted)
lnRMVE	**7.46**	**-3.34**
	(5.81)[a]	**(-6.96)[a]**
lnrGDP	**-5.84**	**2.52**
	(-4.00)[a]	**(4.63)[a]**
oilshrp3	**-24.99**	0
	(-7.67)[a]	(omitted)
Constant	40.72	-19.31

[a]   Significant at 1% level.

TABLE A-2b Oilshrp3 Endogenous Model Error Correction Equation Coefficients, z Values, Significance, R^2

Influence Variable	Predicted Variable						
	Δ(lnrpgas)	Δ(lngas)	Δ(lnequity)	Δ(lnrcmdebt)	Δ(lnRMVE)	Δ(lnrGDP)	oilshrp3
Long-Term Level Effects							
Cointegration	0.0000	0.0000	**0.023**	**-0.018**	**0.096**	**0.013**	0.000
predicted lnrpgas	(NA)	(NA)	**(2.28)[b]**	**(-4.52)[a]**	**(3.19)[a]**	**(3.17)[a]**	(0.84)
Cointegration	0.0000	0.0000	*0.047*	**-0.041**	**0.337**	**0.039**	0.000
predicted lngas	(NA)	(NA)	*(1.81)[c]*	**(-4.03)[a]**	**(4.35)[a]**	**(3.75)[a]**	(0.01)
Short-Term Dislocation (shock)							
Δ(lnrpgas(-1))	0.100	*-0.058*	0.027	0.020	-0.129	-0.002	0.006
	(1.02)	*(-1.93)[c]*	(0.71)	(1.31)	(-1.17)	(-0.15)	(1.79)
Δ(lnrpgas(-2))	-0.023	-0.020	-0.043	0.001	-0.084	0.002	**0.009**
	(-0.25)	(-0.72)	(-1.19)	(0.10)	(-0.81)	(0.13)	**(2.83)[a]**
Δ(lngas(-1))	-0.078	-0.129	0.094	0.042	0.006	-0.011	0.009
	(-0.31)	(-1.67)	(0.96)	(1.04)	(0.03)	(-0.27)	(1.04)
Δ(lngas(-2))	0.112	-0.098	0.040	0.014	0.008	0.055	0.004
	(0.45)	(-1.29)	(0.42)	(0.37)	(0.03)	(1.43)	(0.40)
Δ(lnequity(-1))	0.029	0.069	**0.484**	0.023	**0.405**	**0.062**	0.001
	(0.17)	(1.35)	**(7.48)[a]**	(0.88)	**(2.16)[b]**	**(2.41)[b]**	(0.12)
Δ(lnequity(-2))	0.237	**-0.105**	**0.209**	0.001	-0.142	-0.009	0.005
	(1.40)	**(-2.04)[b]**	**(3.20)[a]**	(0.02)	(-0.75)	(-0.35)	(0.78)
Δ(lnrcmdebt(-1))	-0.030	**0.295**	0.228	**0.241**	**1.197**	**0.311**	0.008
	(-0.06)	**(1.98)[b]**	(1.21)	**(3.14)[a]**	**(2.19)[b]**	**(4.27)[a]**	(0.466)
Δ(lnrcmdebt(-2))	-0.138	-0.219	-0.036	**0.207**	*1.009*	0.043	0.009
	(-0.28)	(-1.45)	(-0.19)	**(2.66)[a]**	*(1.83)[c]*	(0.57)	(0.54)
Δ(lnRMVE(-1))	-0.066	-0.007	-0.026	0.001	**-0.254**	0.001	-0.001
	(-0.94)	(-0.34)	(-0.97)	(0.13)	**(-3.26)[a]**	(0.08)	(-0.27)
Δ(lnRMVE(-2))	0.077	-0.007	0.007	-0.005	-0.044	0.002	0.002
	(1.25)	(-0.38)	(0.31)	(-0.47)	(-0.64)	(0.19)	(1.11)
Δ(lnrGDP(-1))	0.505	0.101	0.019	**0.190**	**2.242**	**0.252**	0.016
	(1.01)	(0.66)	(0.10)	**(2.41)[b]**	**(4.00)[a]**	**(3.27)[a]**	(0.90)
Δ(lnrGDP(-2))	-0.273	0.198	-0.129	0.086	0.538	0.025	-0.018
	(-0.55)	(1.30)	(-0.67)	(1.09)	(0.97)	(0.32)	(-1.05)
Δ(oilshrp3(-1))	**7.321**	0.027	0.894	**-1.170**	1.122	0.497	0.034
	(3.00)[a]	(0.04)	(0.95)	**(-3.04)[a]**	(0.41)	(1.32)	(0.40)
Δ(oilshrp3(-2))	**-6.26**	0.214	-0.227	0.157	-1.218	-0.097	**-0.501**
	(-2.47)[b]	(0.28)	(-0.23)	(0.39)	(-0.43)	(-0.25)	**(-5.60)[a]**

TABLE A-2b (Cont.)

Influence Variable	Predicted Variable						
	Δ(lnrpgas)	Δ(lngas)	Δ(lnequity)	Δ(lnrcmdebt)	Δ(lnRMVE)	Δ(lnrGDP)	oilshrp3
Short-Term Dislocation (shock) (cont.)							
Constant	0.001	0.002	0.000	**0.004**	**-0.036**	0.001	-0.0003
	(0.19)	(0.89)	(0.11)	**(3.26)[a]**	**(-4.37)[a]**	(0.75)	(-1.03)
R-squared	0.182	0.126	0.481	0.594	0.321	0.281	0.177

[a] Significant at 1% level.

[b] Significant at 5% level.

[c] Significant at 10% level.

Note—This model was estimated by P. Whitman, using E-Views. In comparative tests of E-Views and Stata for model A1b the R-squared values created by E-Views differed slightly from those generated by Stata.

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